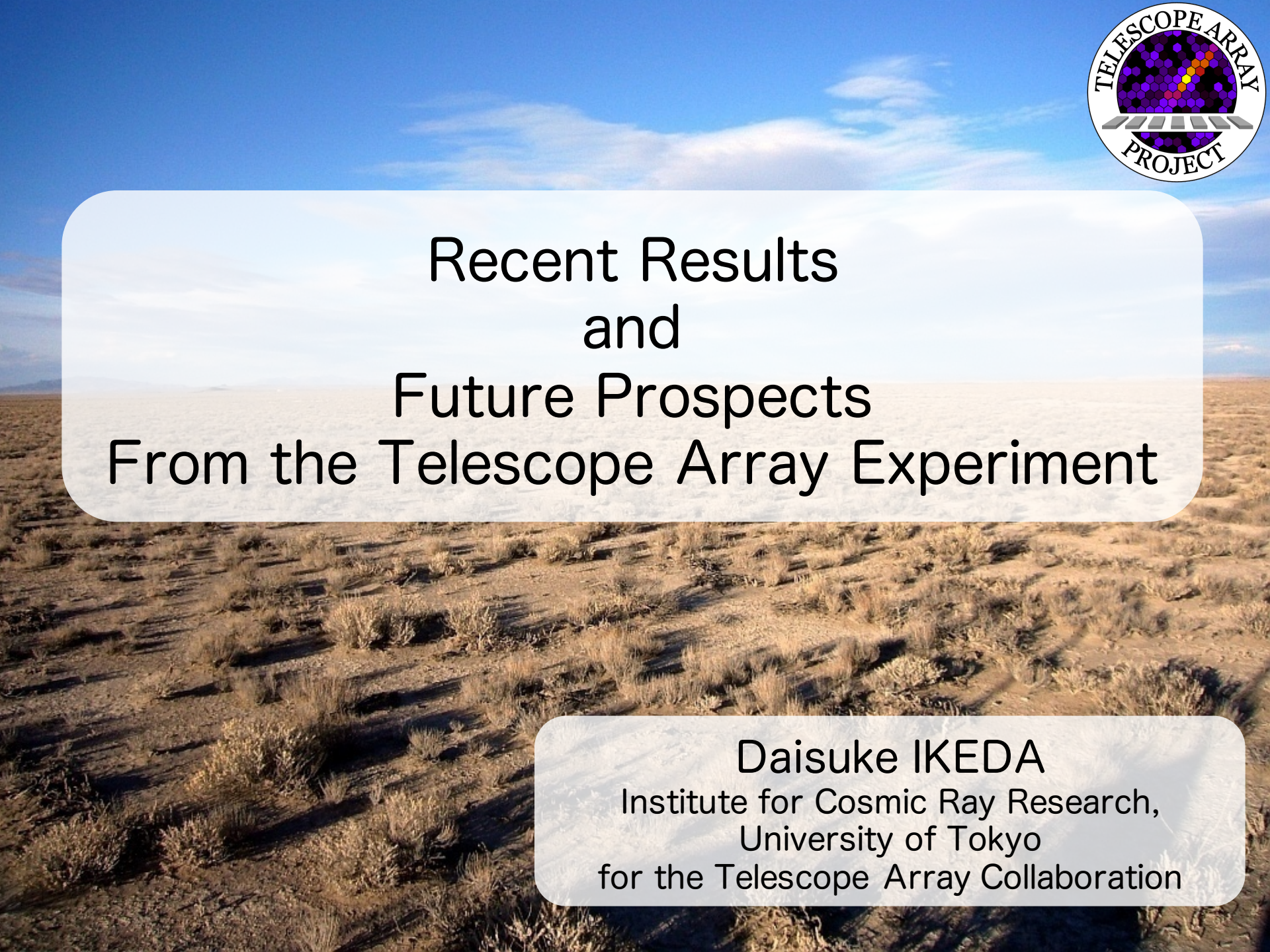

Recent Results and Future Prospects From the Telescope Array Experiment

Daisuke IKEDA
Institute for Cosmic Ray Research,
University of Tokyo
for the Telescope Array Collaboration

Telescope Array Collaboration

5 countries, 33 institutions, 124 members

RU Abbasi[1], M Abe[13], T Abu-Zayyad[1], M Allen[1], R Anderson[1], R Azuma[2], E Barcikowski[1], JW Belz[1], DR Bergman[1], SA Blake[1], R Cady[1], MJ Chae[3], BG Cheon[4], J Chiba[5], M Chikawa[6], WR Cho[7], T Fujii[8], M Fukushima[8,9], T Goto[10], W Hanlon[1], Y Hayashi[10], N Hayashida[11], K Hibino[11], K Honda[12],D Ikeda[8], N Inoue[13], T Ishii[12], R Ishimori[2], H Ito[14], D Ivanov[1], CCH Jui[1], K Kadota[16], F Kakimoto[2], O Kalashev[17], K Kasahara[18], H Kawai[19], S Kawakami[10], S Kawana[13], K Kawata[8], E Kido[8], HB Kim[4], JH Kim[1], JH Kim[25], S Kitamura[2], Y Kitamura[2], V Kuzmin[17], YJ Kwon[7], J Lan[1], SI Lim[3], JP Lundquist[1], K Machida[12], K Martens[9], T Matsuda[20], T Matsuyama[10], JN Matthews[1], M Minamino[10], K Mukai[12], I Myers[1], K Nagasawa[13], S Nagataki[14],T Nakamura[21], T Nonaka[8], A Nozato[6], S Ogio[10], J Ogura[2], M Ohnishi[8], H Ohoka[8], K Oki[8], T Okuda[22], M Ono[14], A Oshima[10], S Ozawa[18], IH Park[23], MS Pshirkov[24], DC Rodriguez[1], G Rubtsov[17], D Ryu[25], H Sagawa[8], N Sakurai[10], AL Sampson[1], LM Scott[15], PD Shah[1], F Shibata[12], T Shibata[8], H Shimodaira[8], BK Shin[4], JD Smith[1], P Sokolsky[1], RW Springer[1], BT Stokes[1], SR Stratton[1,15], TA Stroman[1], T Suzawa[13], M Takamura[5], M Takeda[8], R Takeishi[8], A Taketa[26], M Takita[8], Y Tameda[11], H Tanaka[10], K Tanaka[27], M Tanaka[20], SB Thomas[1], GB Thomson[1], P Tinyakov[17,24], I Tkachev[17], H Tokuno[2], T Tomida[28], S Troitsky[17], Y Tsunesada[2], K Tsutsumi[2], Y Uchihori[29], S Udo[11], F Urban[24], G Vasiloff[1], T Wong[1], R Yamane[10], H Yamaoka[20], K Yamazaki[10], J Yang[3], K Yashiro[5], Y Yoneda[10], S Yoshida[19], H Yoshii[30], R Zollinger[1], Z Zundel[1]

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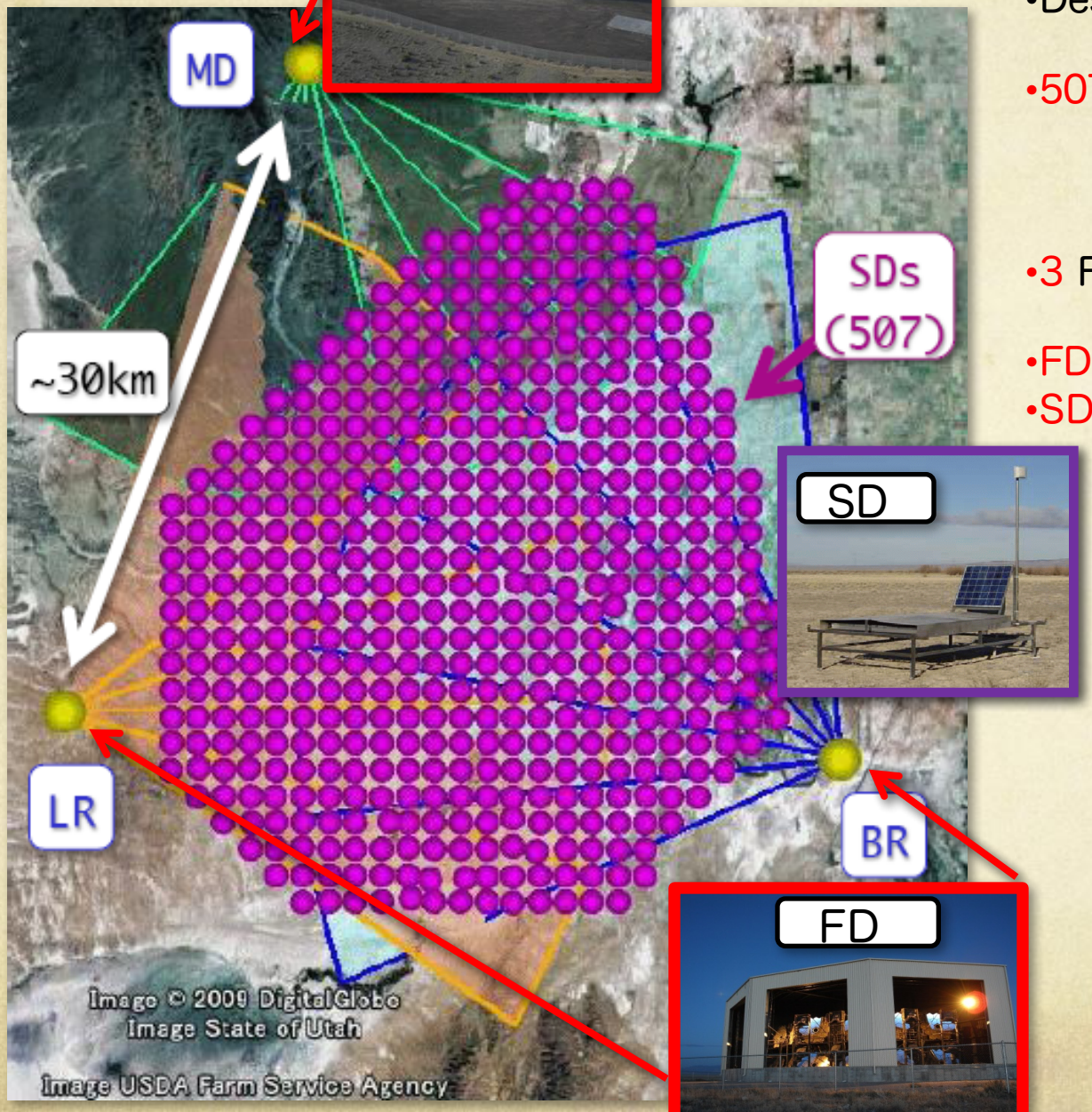
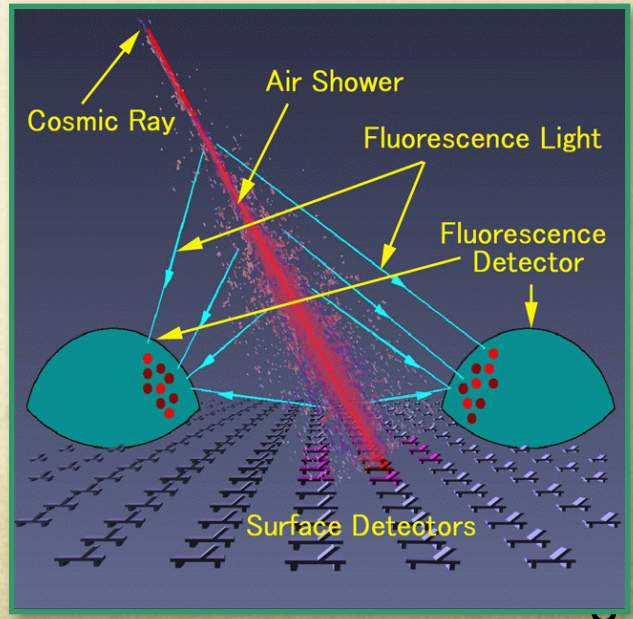
USA, Japan, Korea, Russia, Belgium

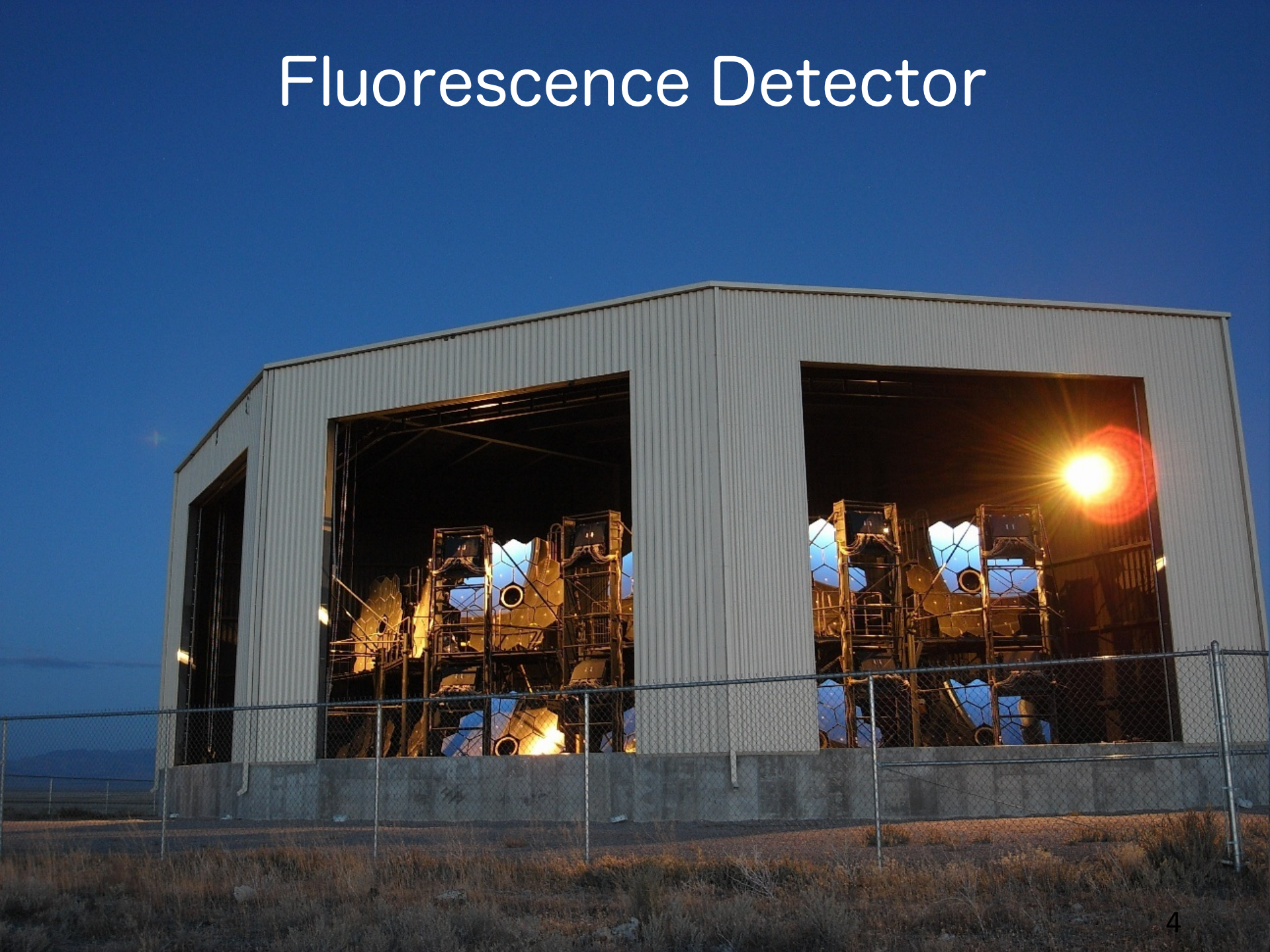
Telescope Array Experiment



- Desert in Utah, US (1400m a.s.l.)
- 507 Surface Detectors (SDs)
  - Two layers of Plastic scintillator ($3m^2$)
  - 1.2km spacing
- 3 Fluorescence Detectors (FDs)
- FD observation : from Nov 2007
- SD observation : from May 2008

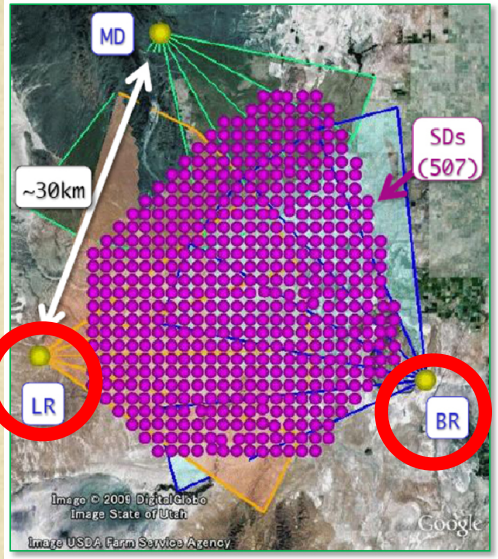


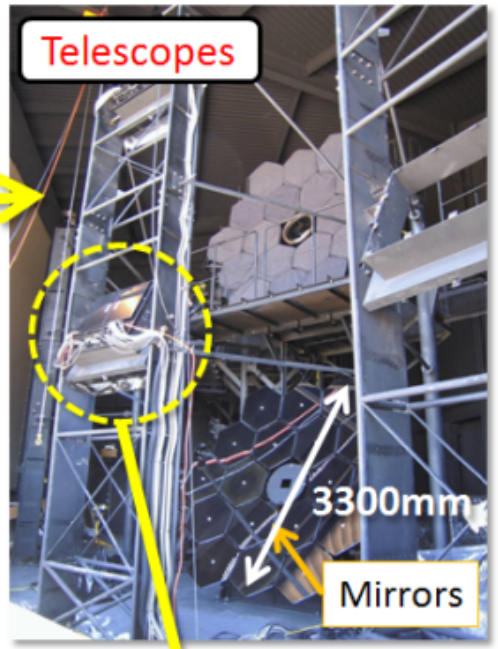
Fluorescence Detector

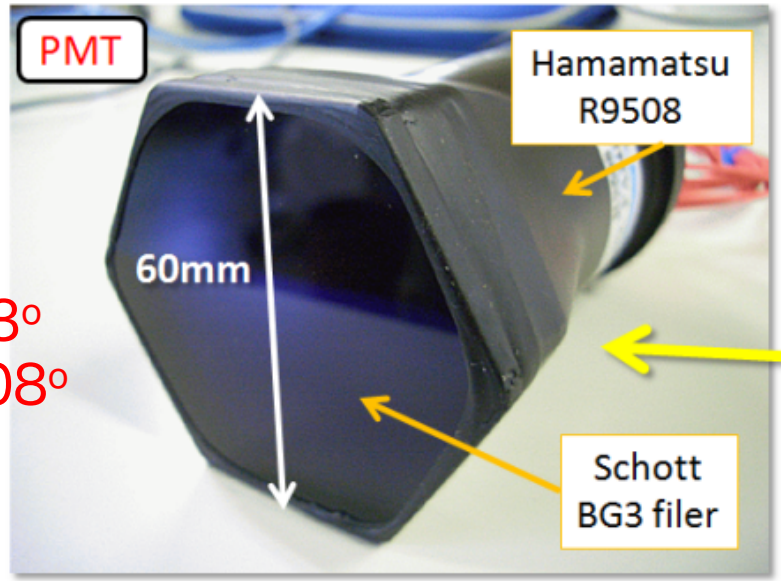


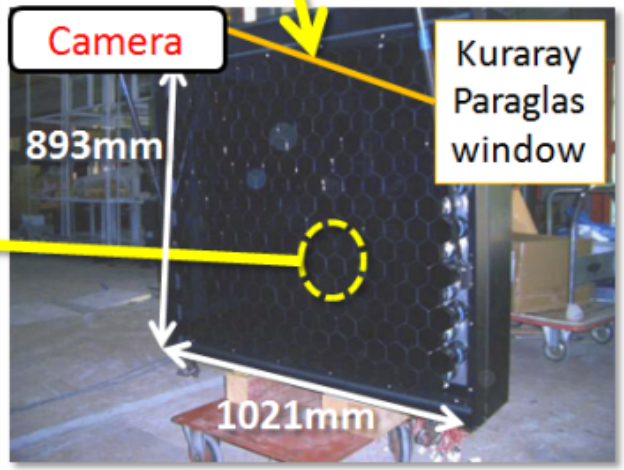
Fluorescence Detector station at BR/LR site

BR/LR site：new telescopes for TA





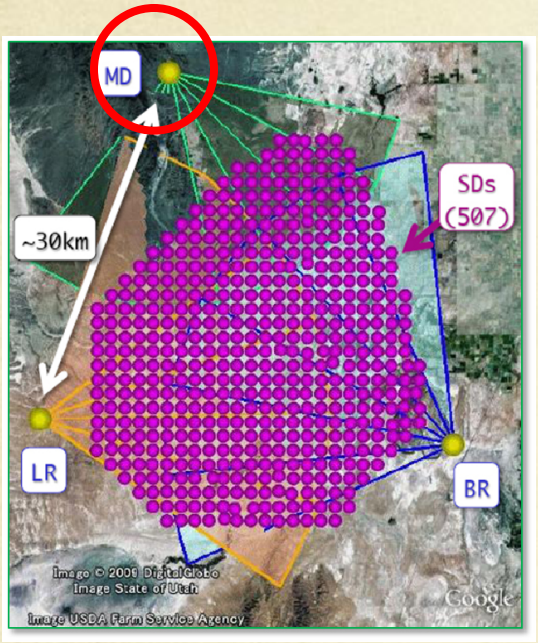




Field of View:

- Elevaton:3~33°
- Horizontal: 108°

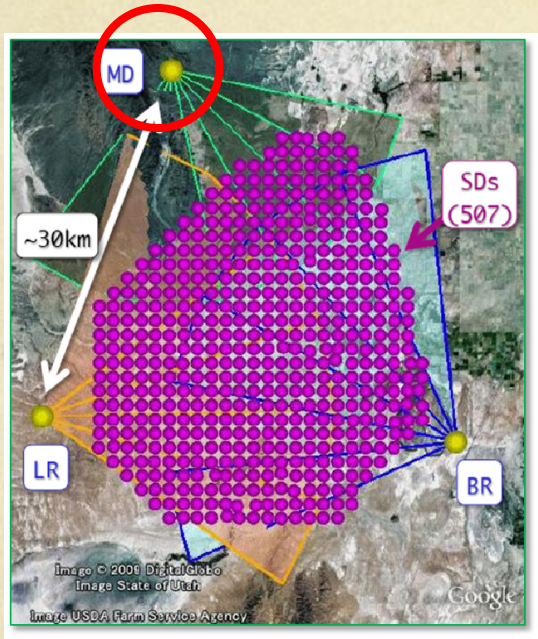
Fluorescence Detector station at MD site

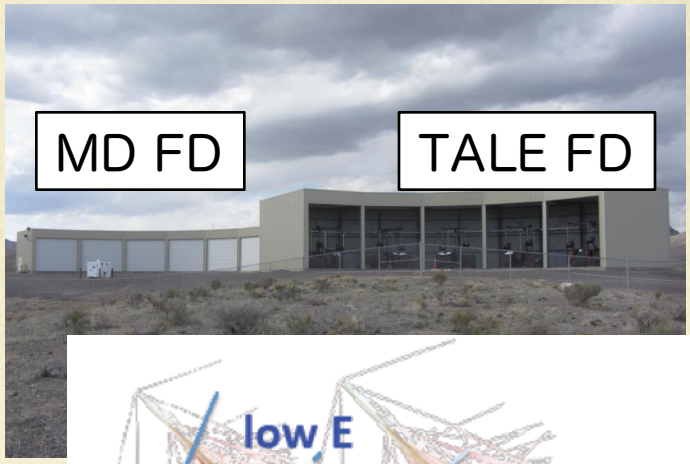


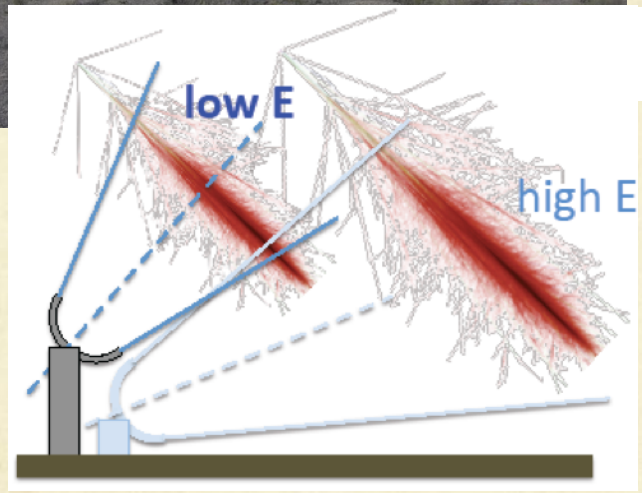
Transferred from HiRes

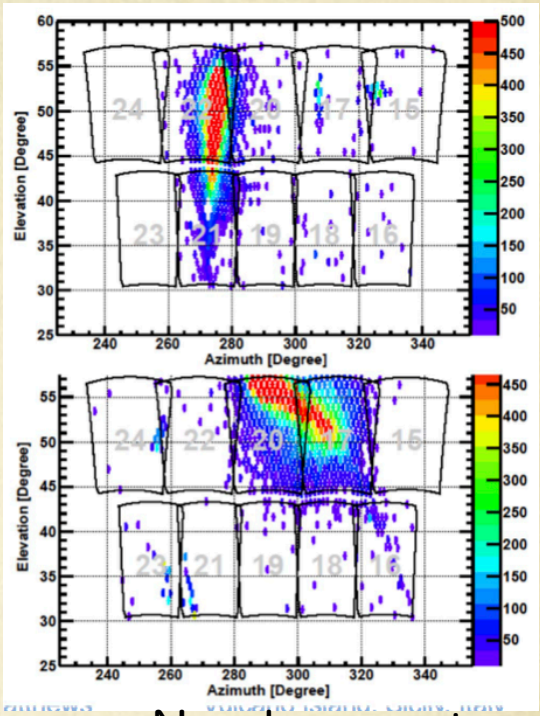
- 14 cameras/station
- 256 PMTs/camera
- 3°-31° elevation with 1° pixel
- 114° in azimuth
- 5.2m² mirror
- S/H electronics

TALE FD: TA Low Energy Extension

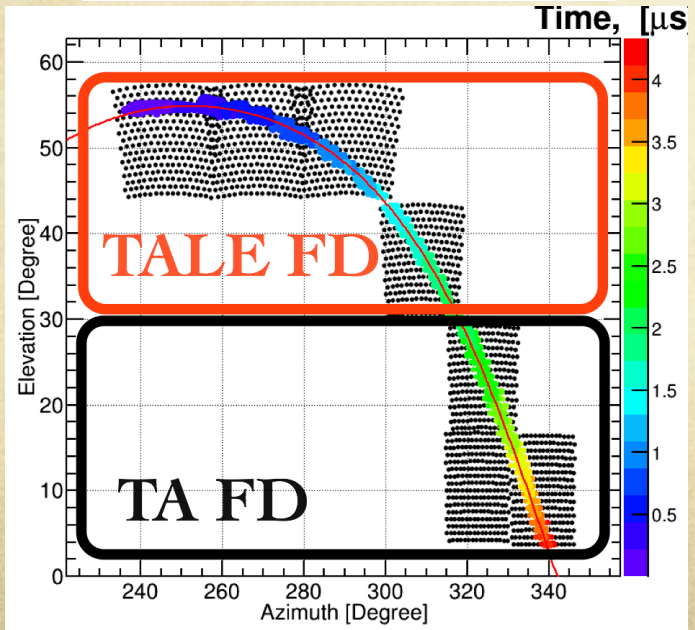








Nearby events with Cherenkov

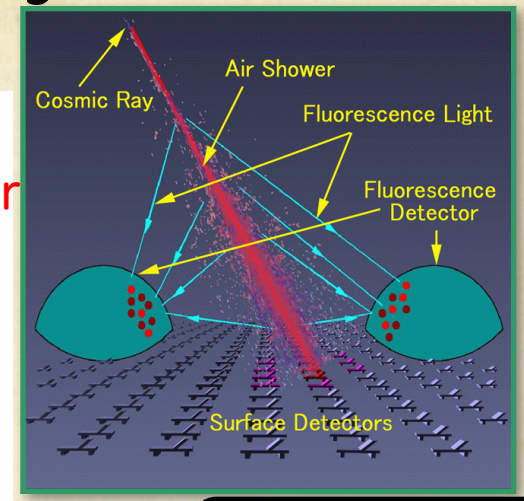


TALE FD

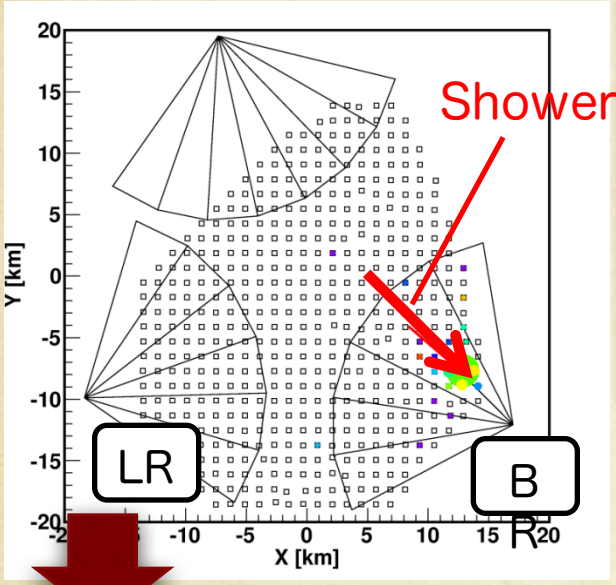
- 10 telescopes
- High elevation angle (31-59 degrees) to see low energy showers
- Observation was started since fall 2013

Shower Analysis of FD

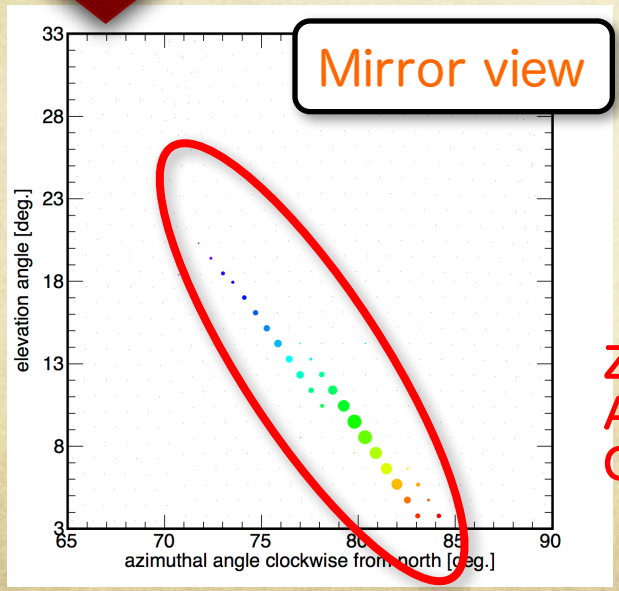
Resolutions (Hybrid):
~1 degrees of arrival direction
~7% of energy
~ 20g/cm2 for Xmax



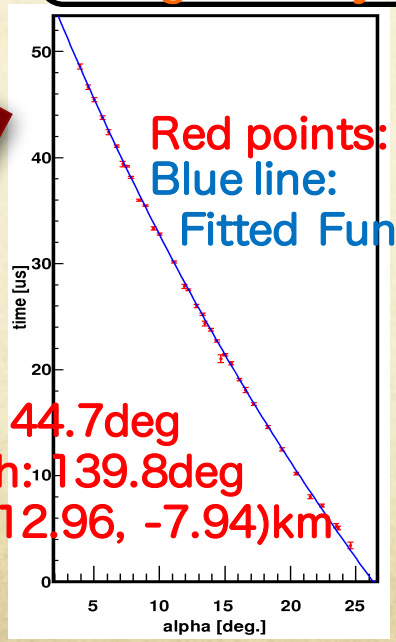
Shower geometry reconstruction:
- Stereo : crossing of two shower-detector planes
- Monocular : timing information of each PMT
- Hybrid : monocular + SD timing



Mirror view



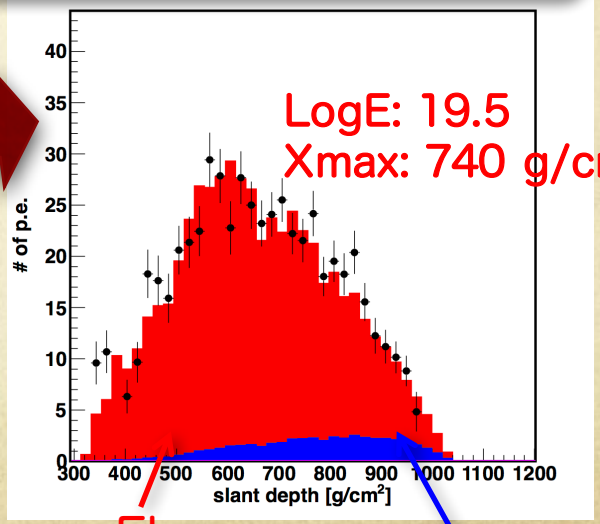
Timing Fit for geometry



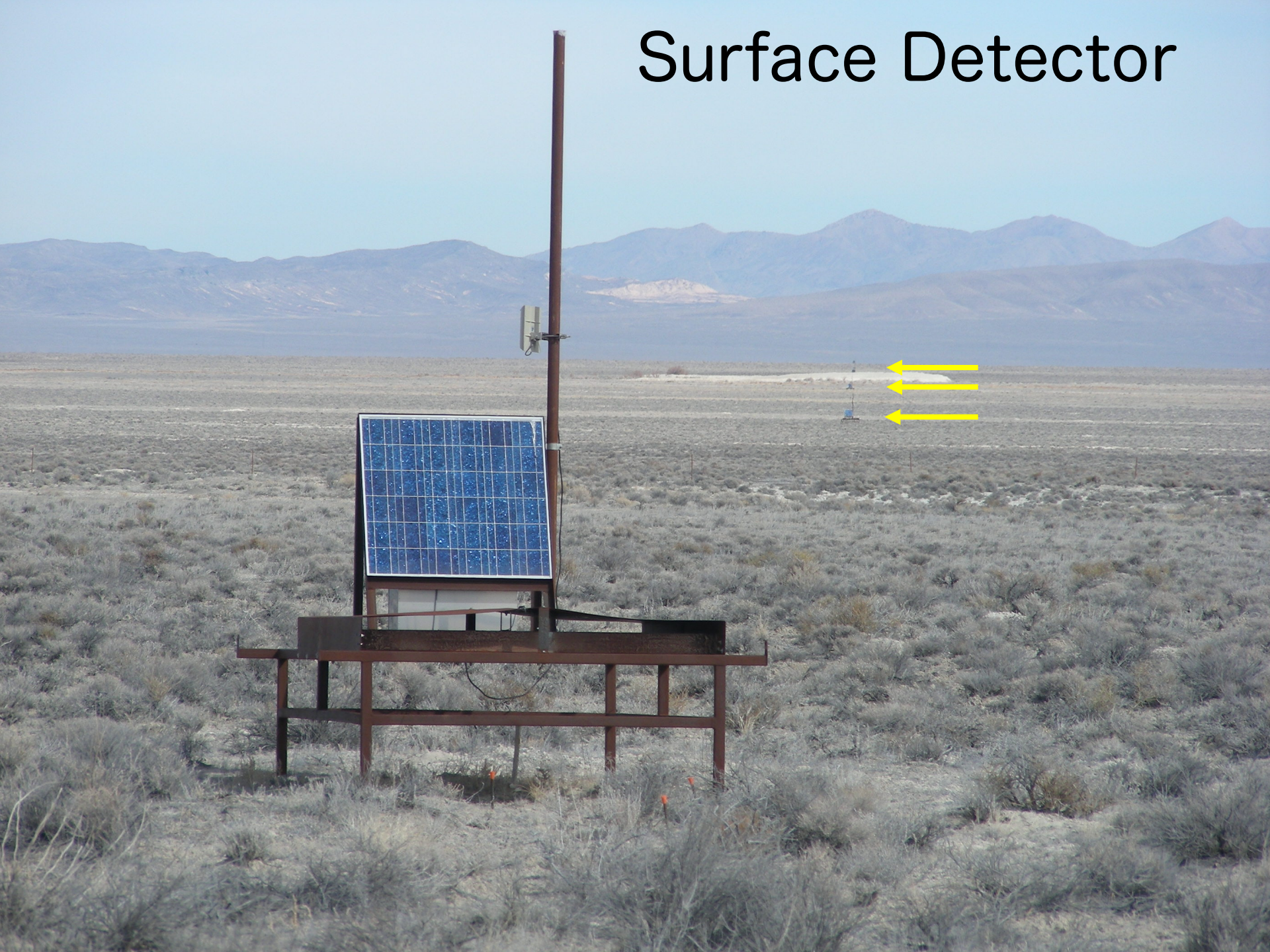
Red points: Data
Blue line: Fitted Function

Zenith: 44.7deg
Azimuth: 139.8deg
Core: (12.96, -7.94)km

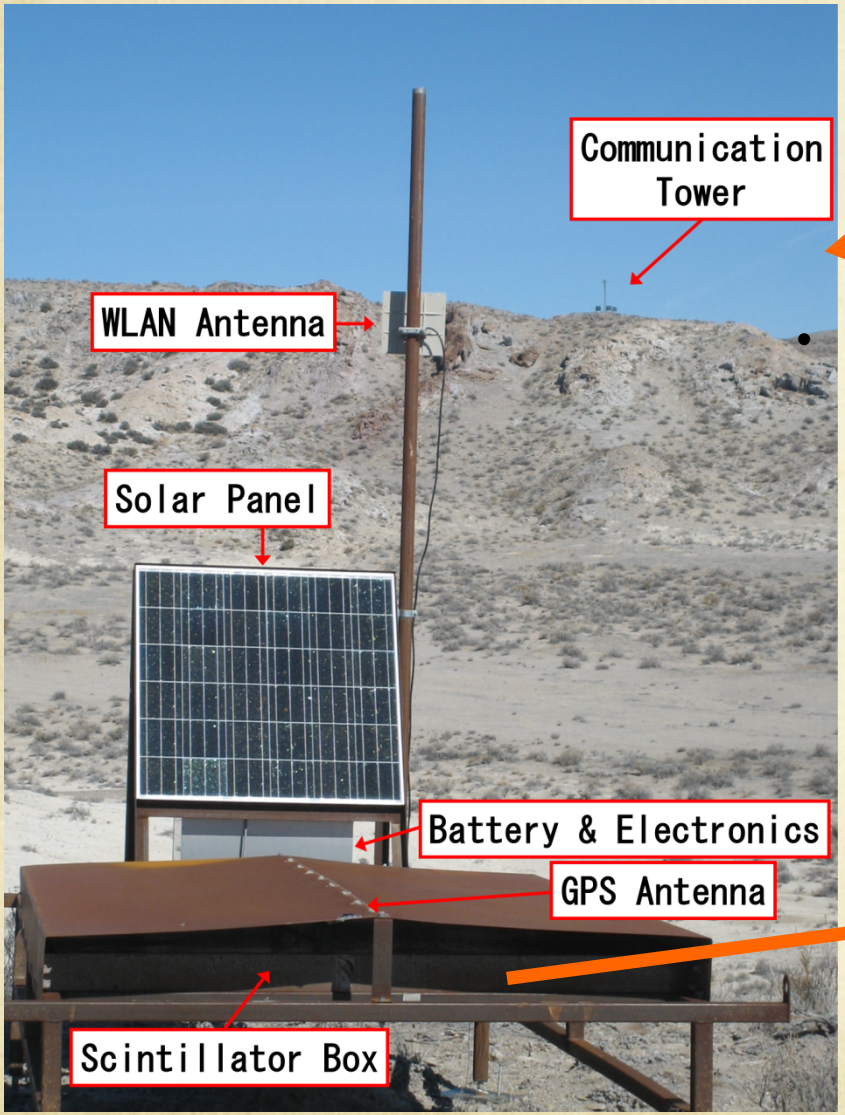
Profile Fit by Inverse Monte Carlo

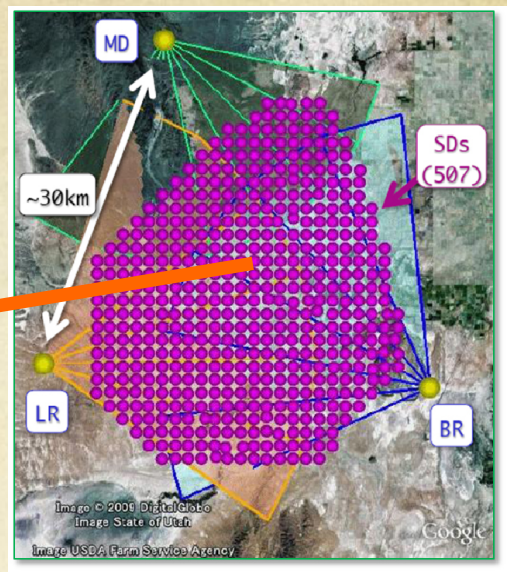


Fluorescence
Scattered Cherenkov

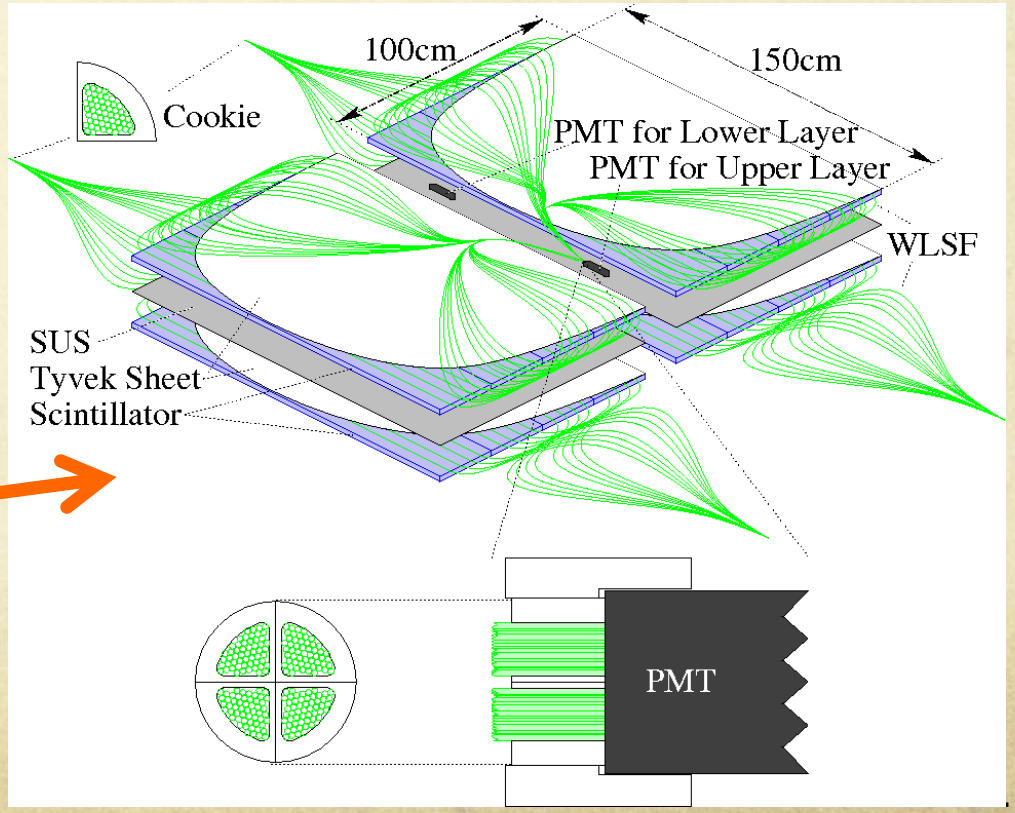

Surface Detector

Surface Detector array





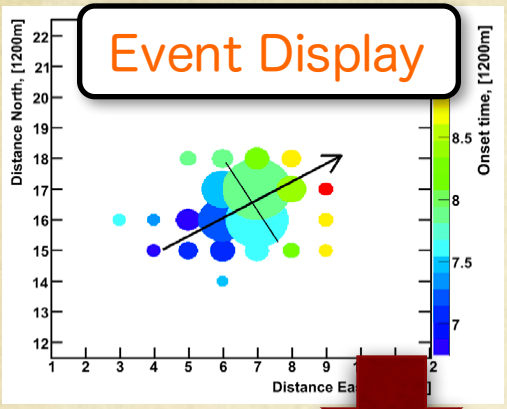
- Two layers of the 3m^2 plastic scintillators

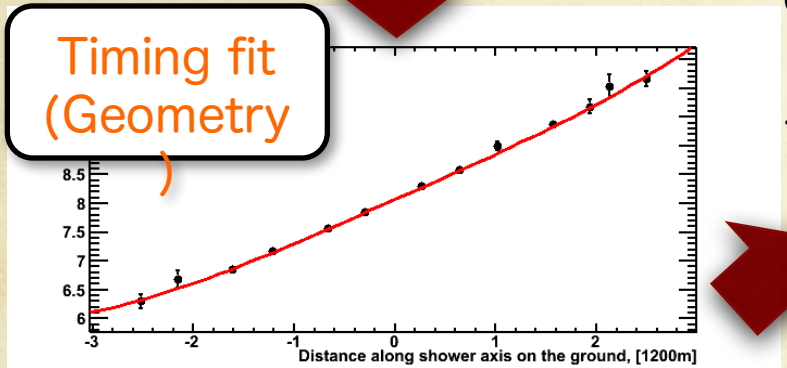


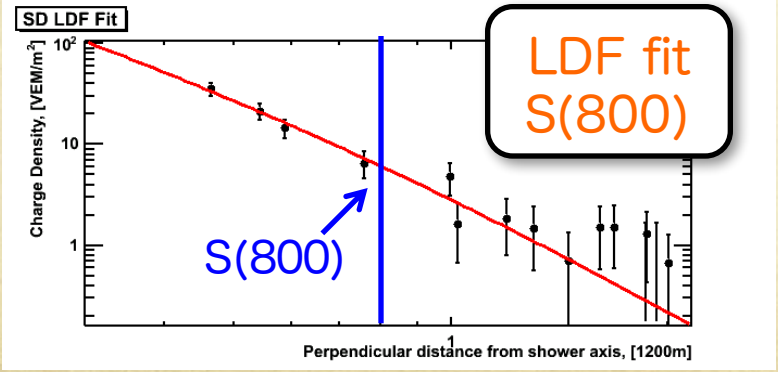
Shower Analysis in SD

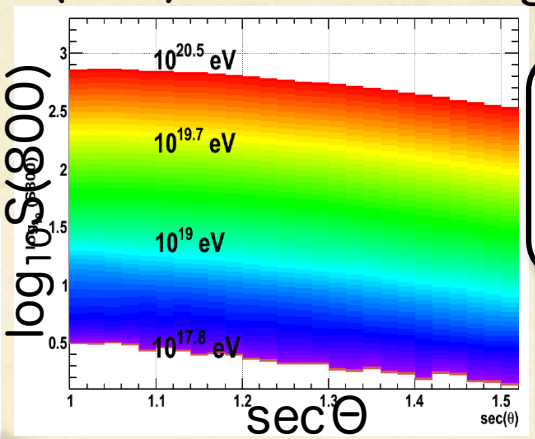
Lateral distribution at the ground

- Geometry: Time fit (~1.5deg.)
- Energy $E_{SD}(MC)$: Primary estimated by S(800) and Zenith angle by using MC (~20%)



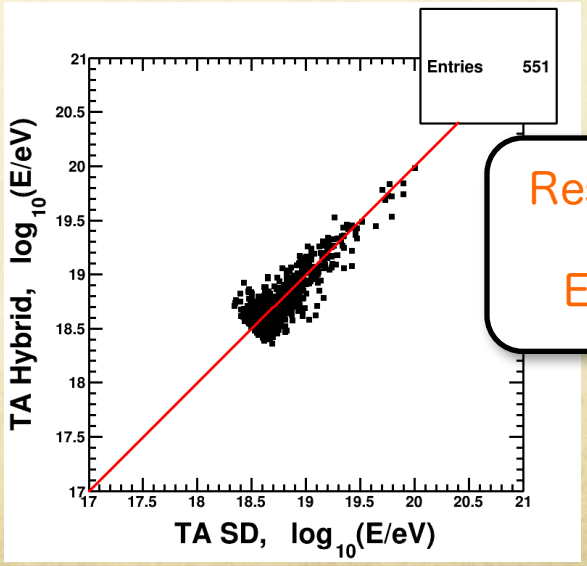






Energy table
Constructed from MC
(Corsika, Proton)

$E_{SD}(MC)$

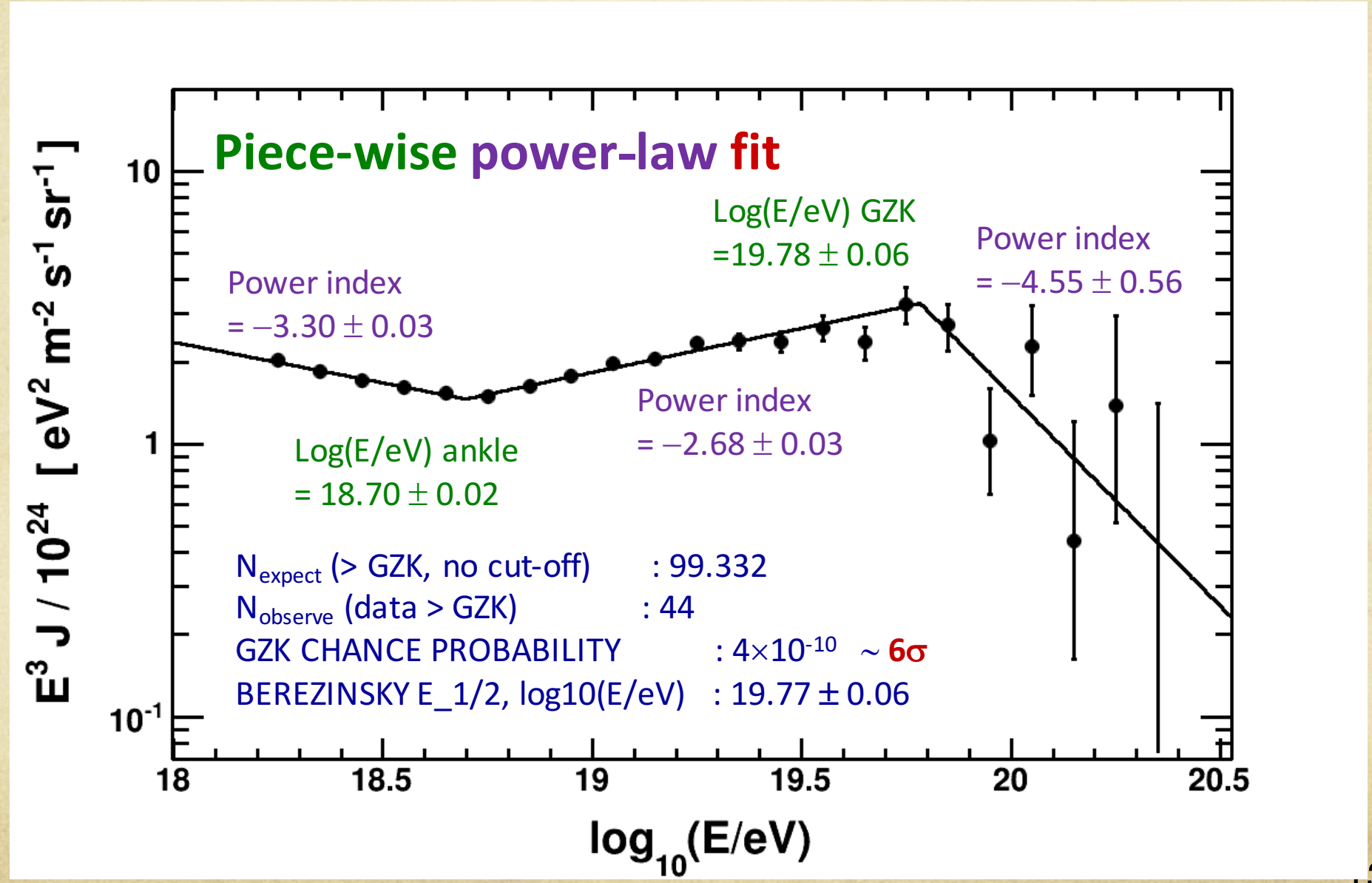


Rescale the SD energy
to the FD energy
$E_{FD} = E_{SD}(MC)/1.27$

Energy

Energy Spectrum

TA SD 7 year spectrum



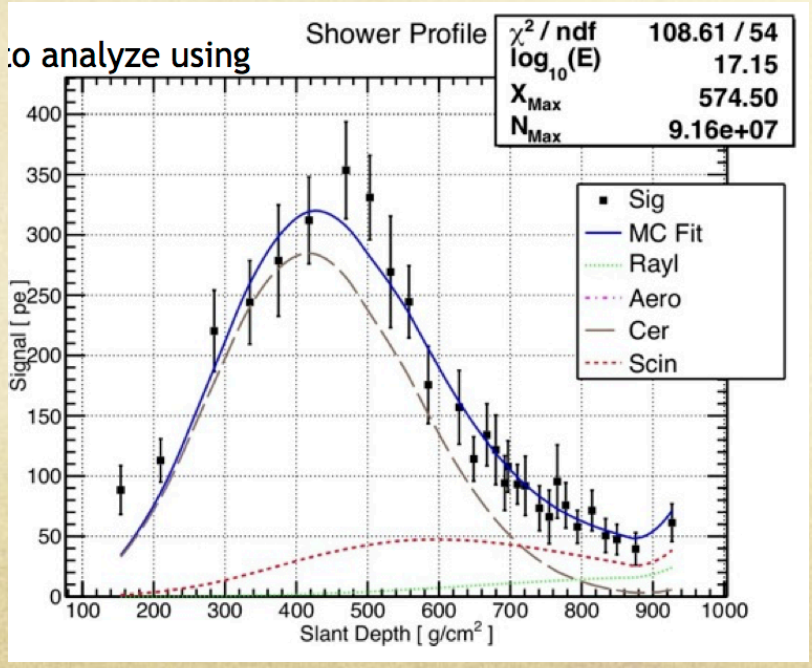
Going below 10^{18}eV: TALE FD

- Events with high Cherenkov fraction used to be discarded by previous experiments
- Have learned how to analyze using Profile constrained Geometry Fit (PCGF) method

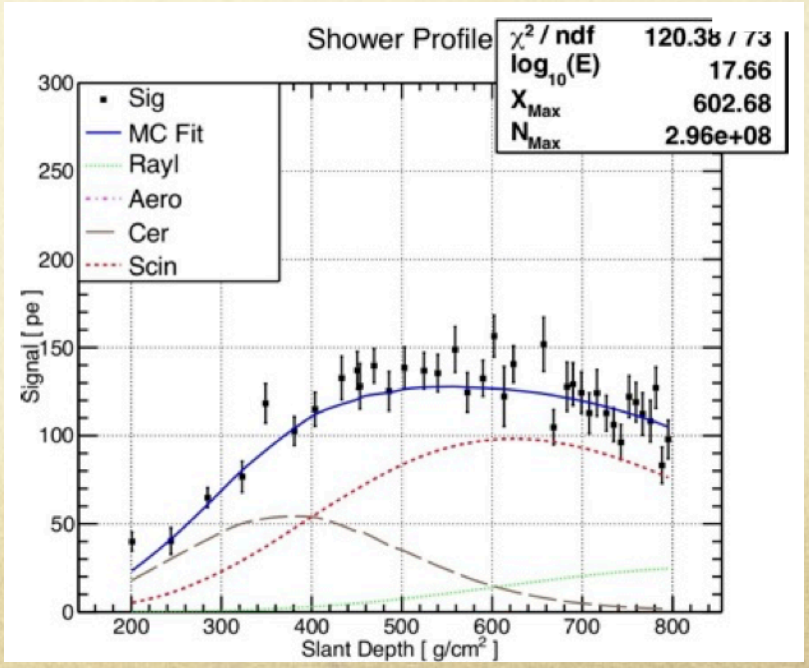
Energy resolution: ~15%
Xmax resolution: ~40g/cm^2

- FD monocular mode
- After the construction of TALE SD, those are improved by the Hybrid technique

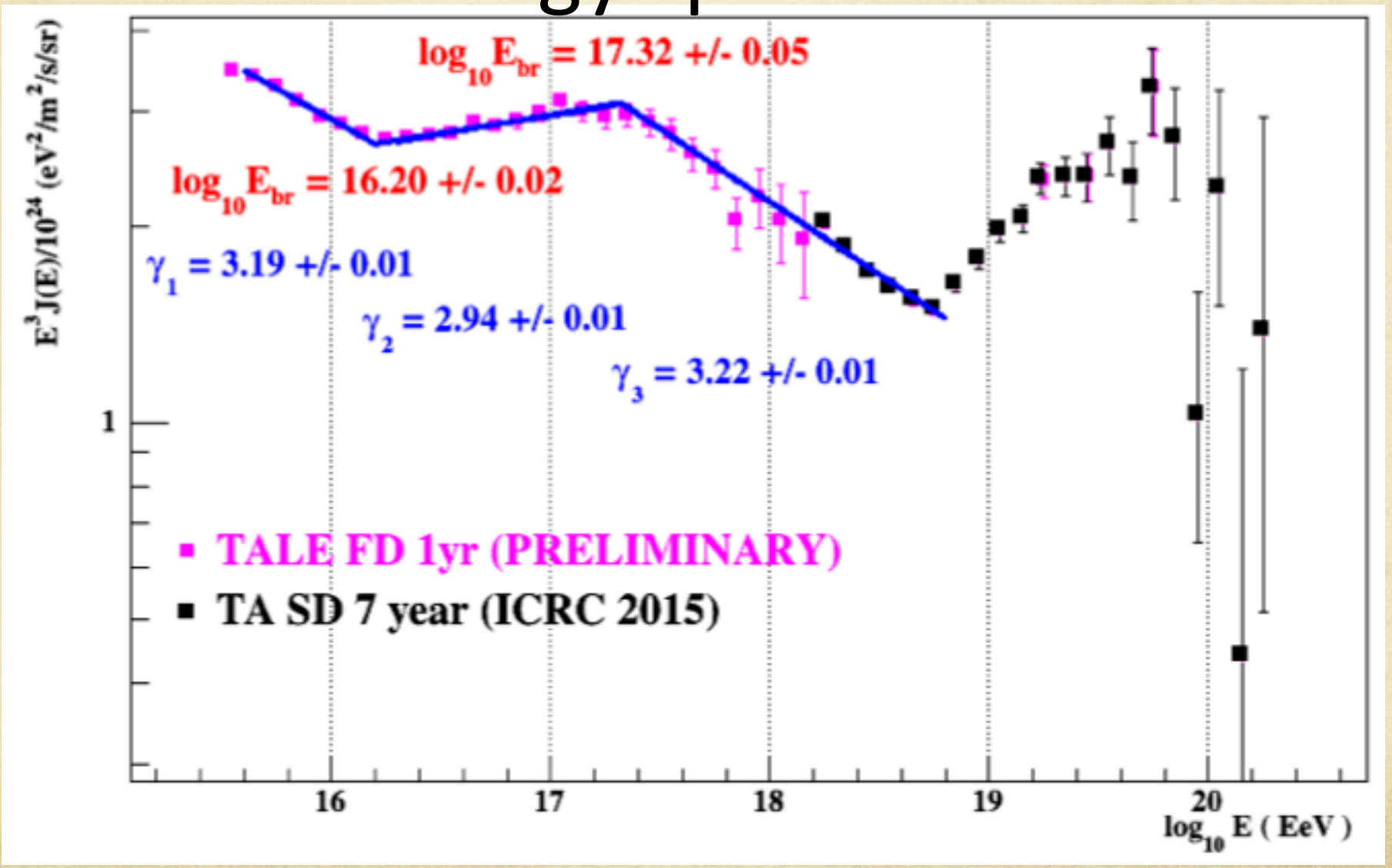
Cherenkov event



Mixed (Fluorescence + Cherenkov)

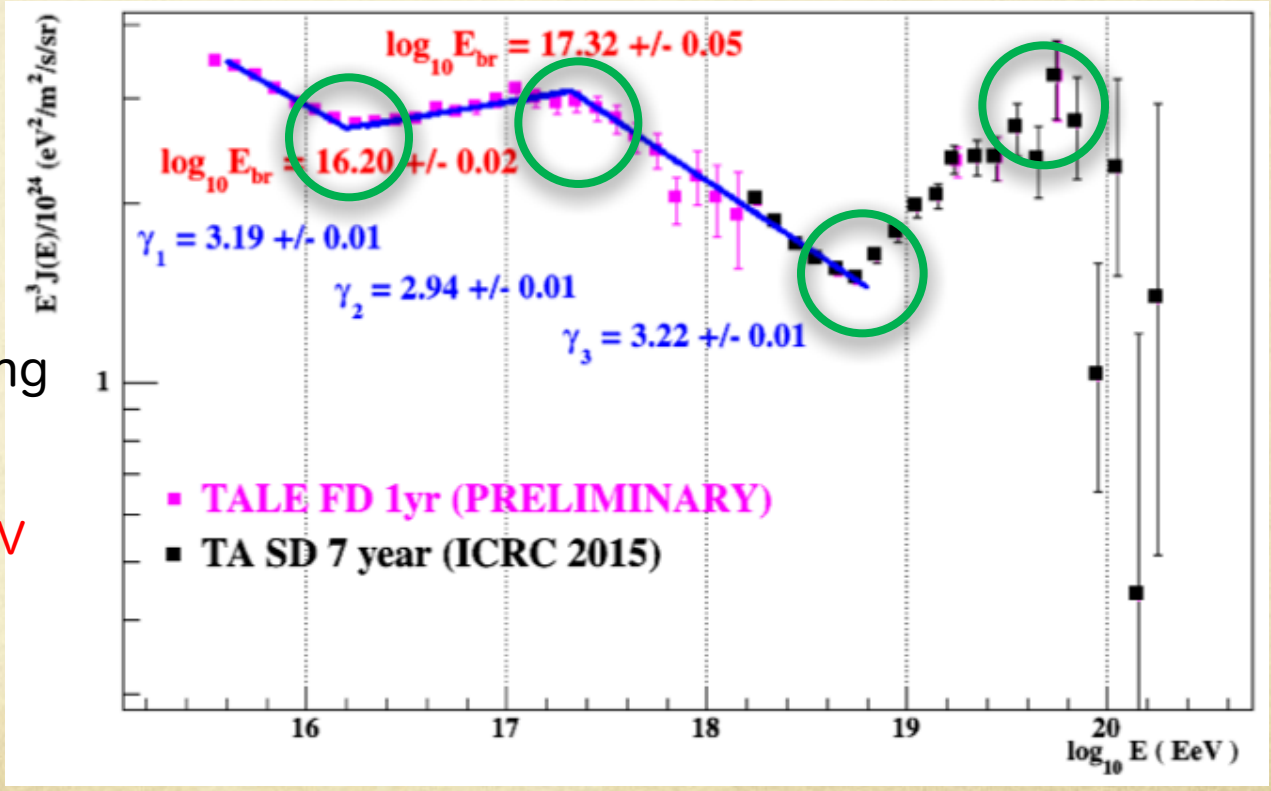


TA SD 7yr +TALE 1yr energy spectrum



A single unified energy scale for the measurement of four features

Study the **transition region** from Galactic to Extra-galactic cosmic ray flux

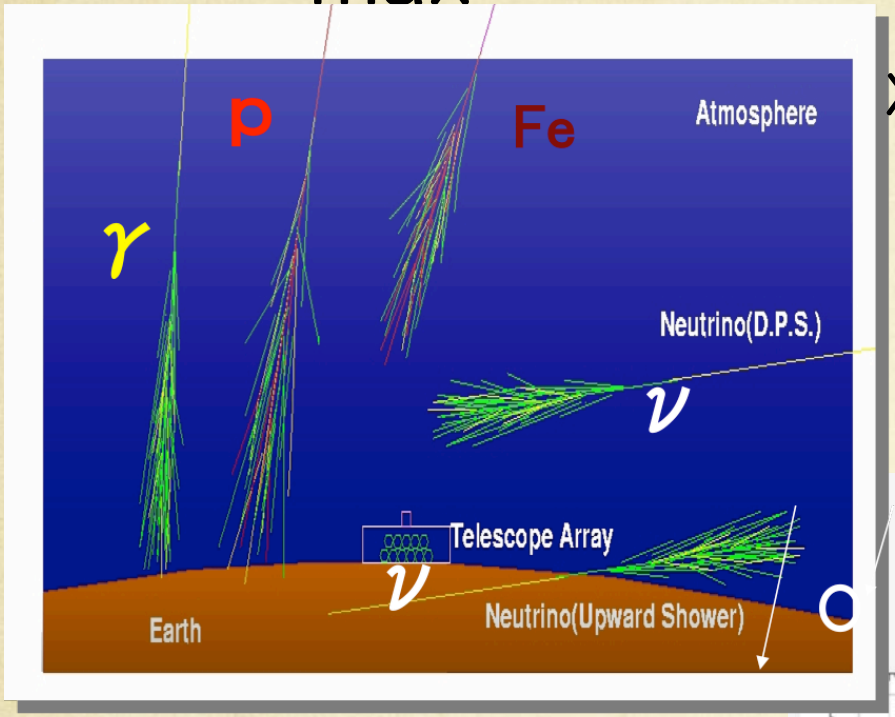


Extended coverage including four cosmic ray spectral features in the UHECR

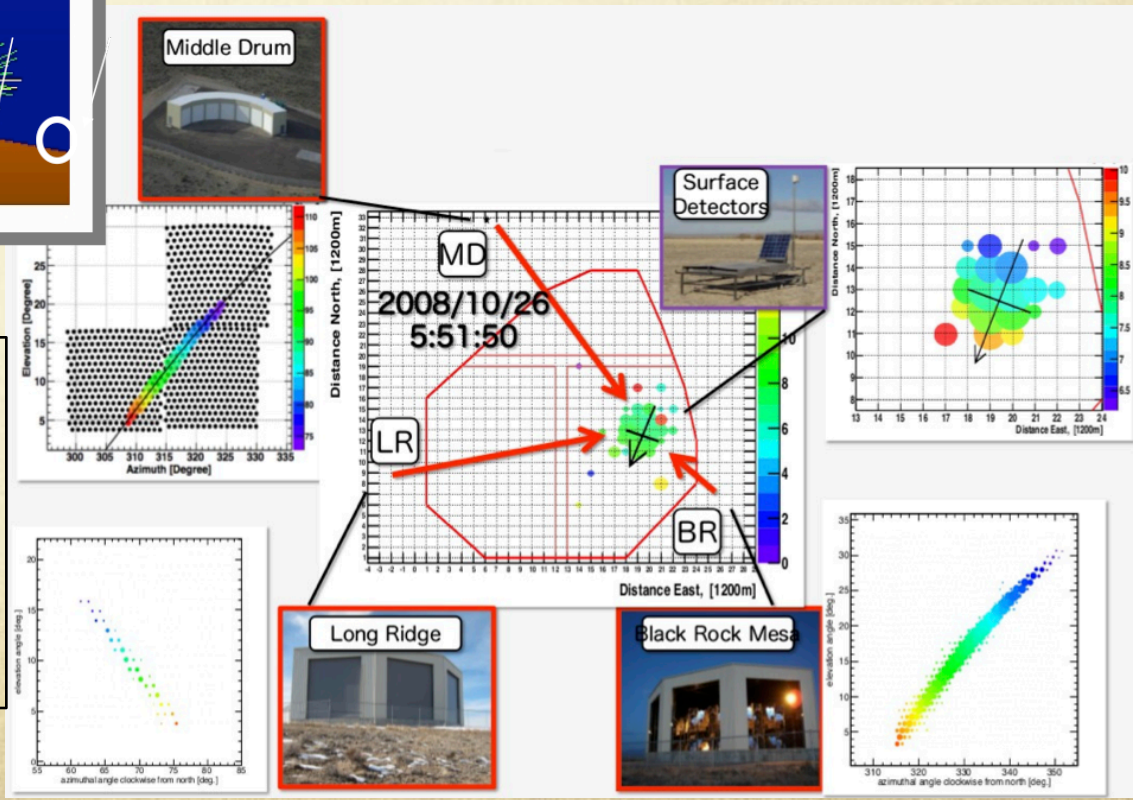
- GZK? suppression $10^{19.78}$ eV
- Ankle $10^{18.7}$ eV
- Second Knee $10^{17.3}$eV
- Low-energy ankle $10^{16.3}$eV

Composition

X_{max} measurement in TA



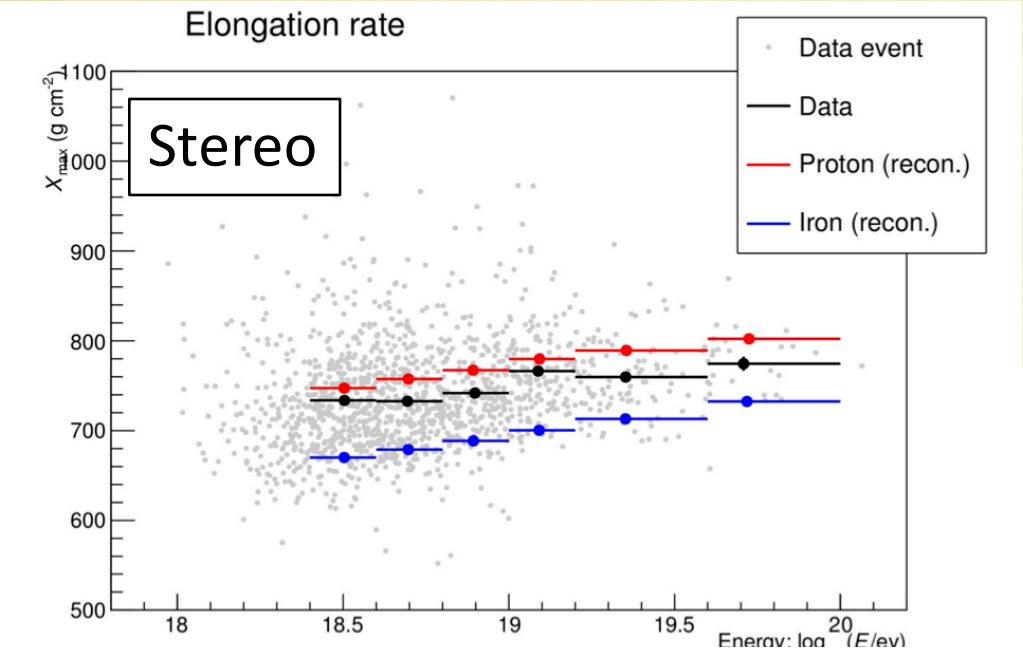
Xmax, depth of the shower maximum, is the composition-sensitive parameter

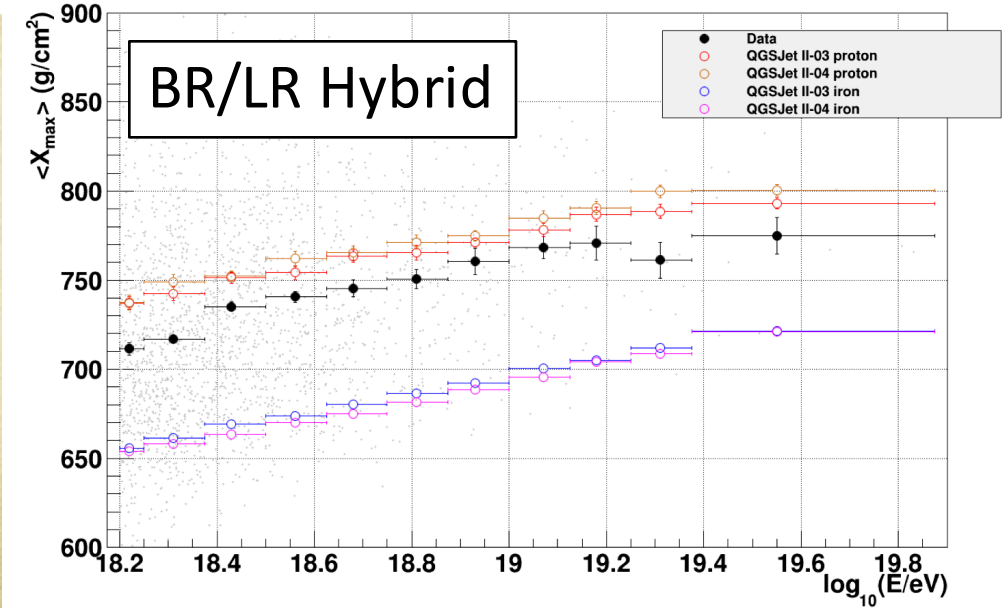


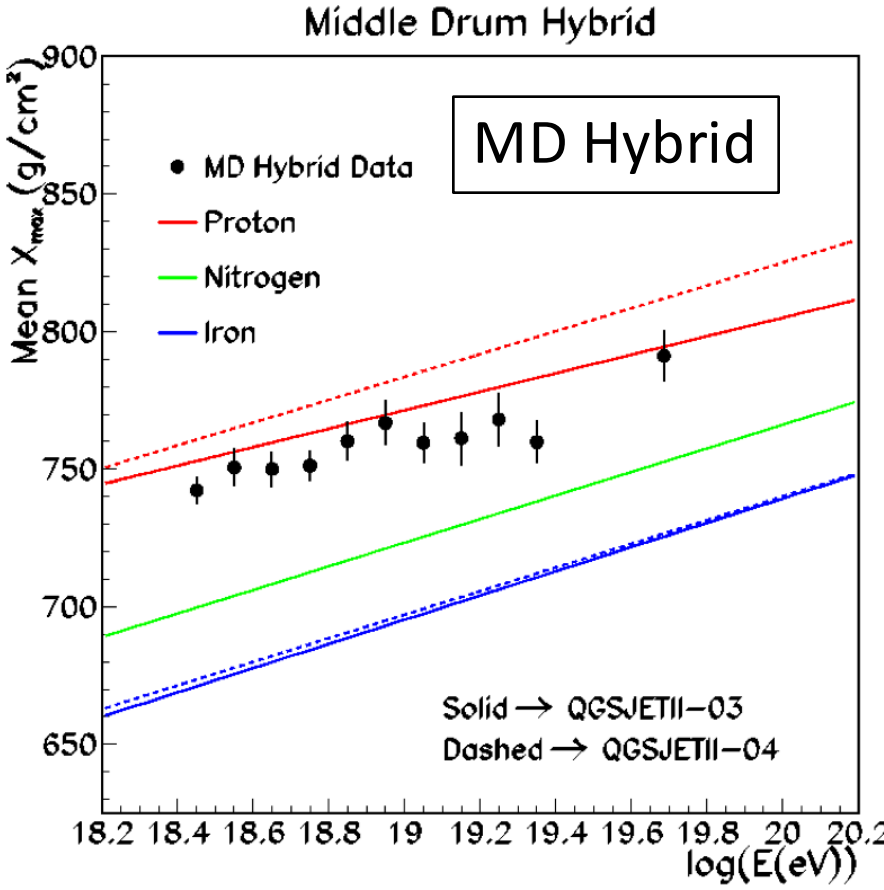
Multiple X_{max} measurements for the systematic cross check

- Stereo
- MD Hybrid
- BR/LR Hybrid
- (Monocular)

Results of $\langle X_{max} \rangle$ measurements

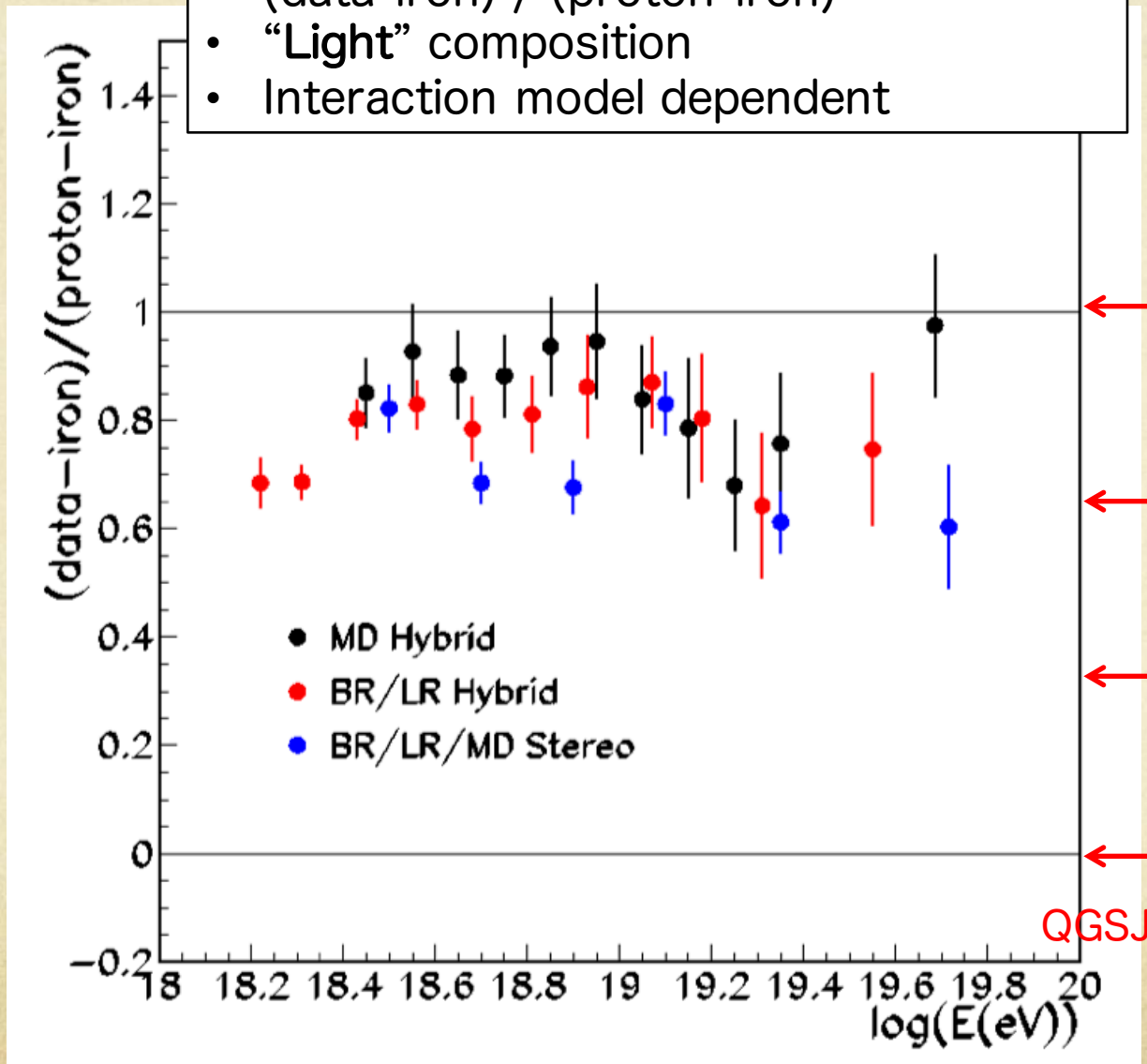






Comparison with the model

- Comparison with QGSJET-II-03 model
- (data-iron) / (proton-iron)
- "**Light**" composition
- Interaction model dependent



← P

← P ← He

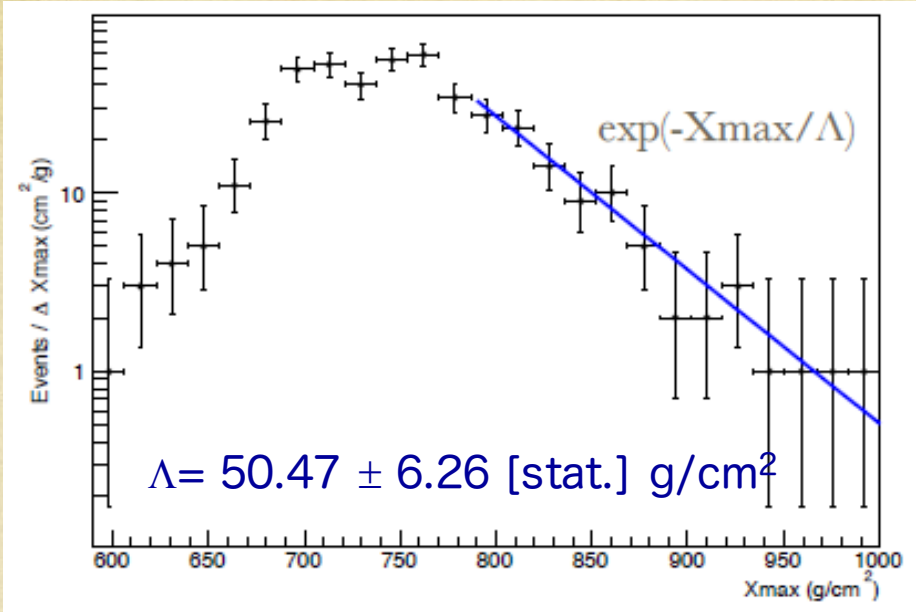
← He ← N

← N

← Fe ← Fe

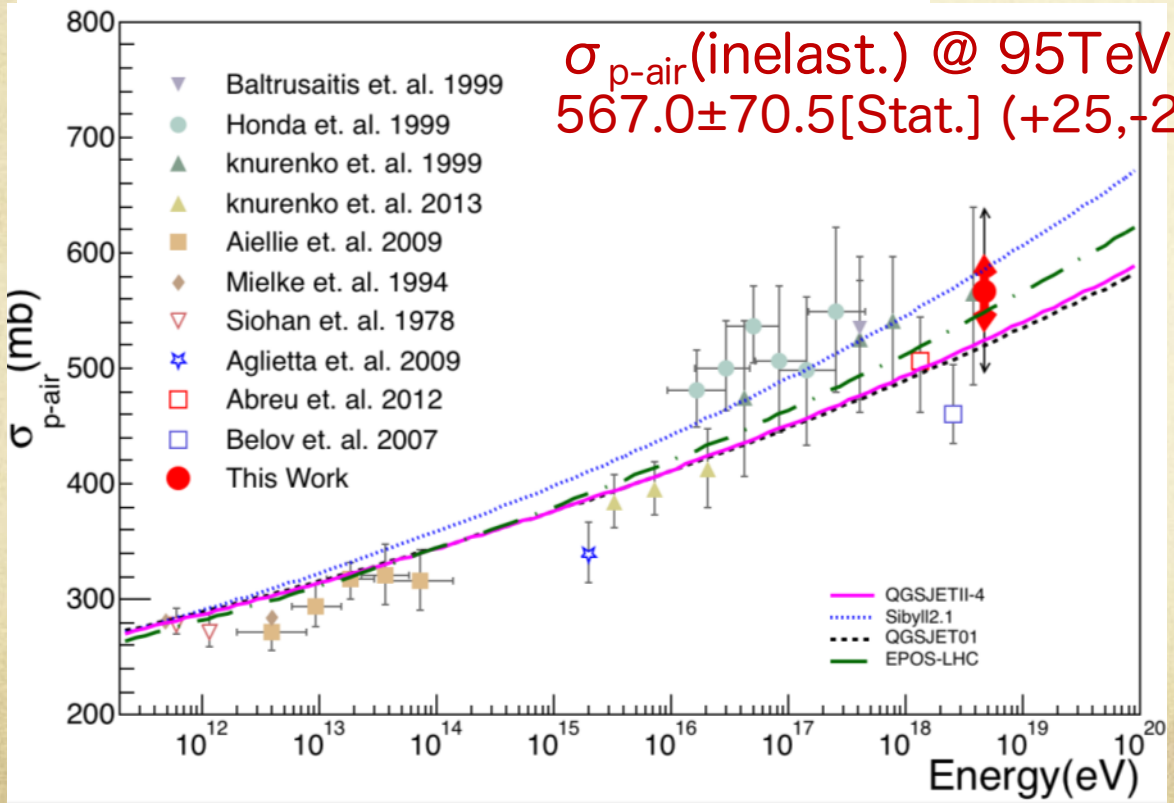
QGSJET-II-03 EPOS-LHC

p-air cross section



Using deeply penetrating particles
→ the tail of Xmax distribution

$\Lambda = K\Lambda_{p\text{-}air} = K(14.45\ m_p/\sigma_{p\text{-}air})$
K: Model dependent factor

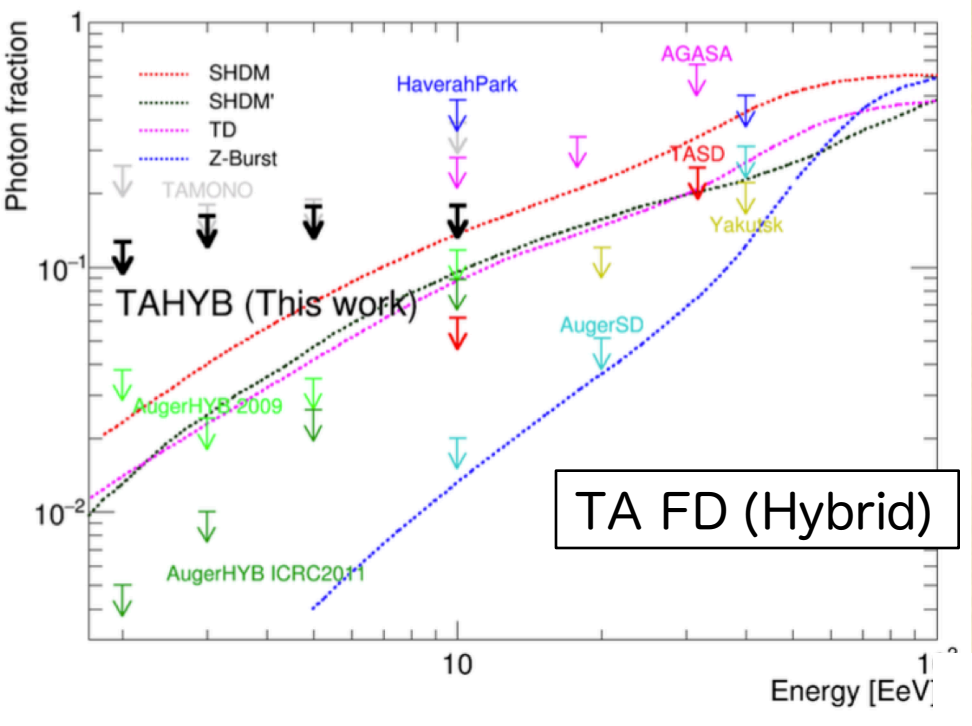


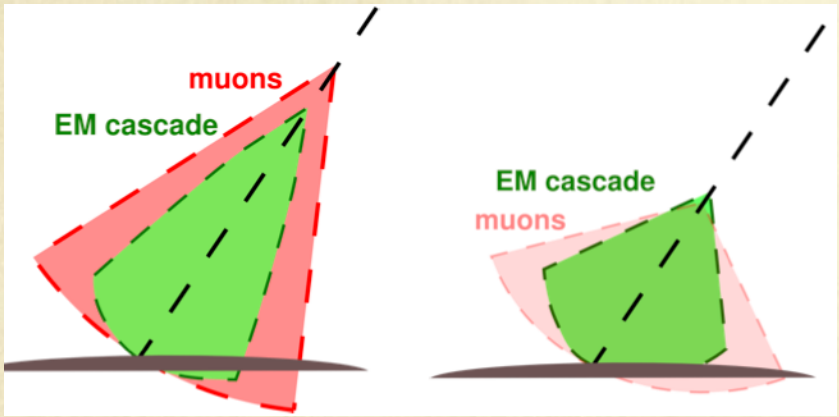
$\sigma_{p\text{-}air}$(inelast.) @ 95TeV of √S is
567.0±70.5[Stat.] (+25,-29)[Sys.] mb

sources	Systematic [mb]
Model	+- 17
20% He	+18
Gamma < 1%	-23
Total	(+25, -29)

UHE photon

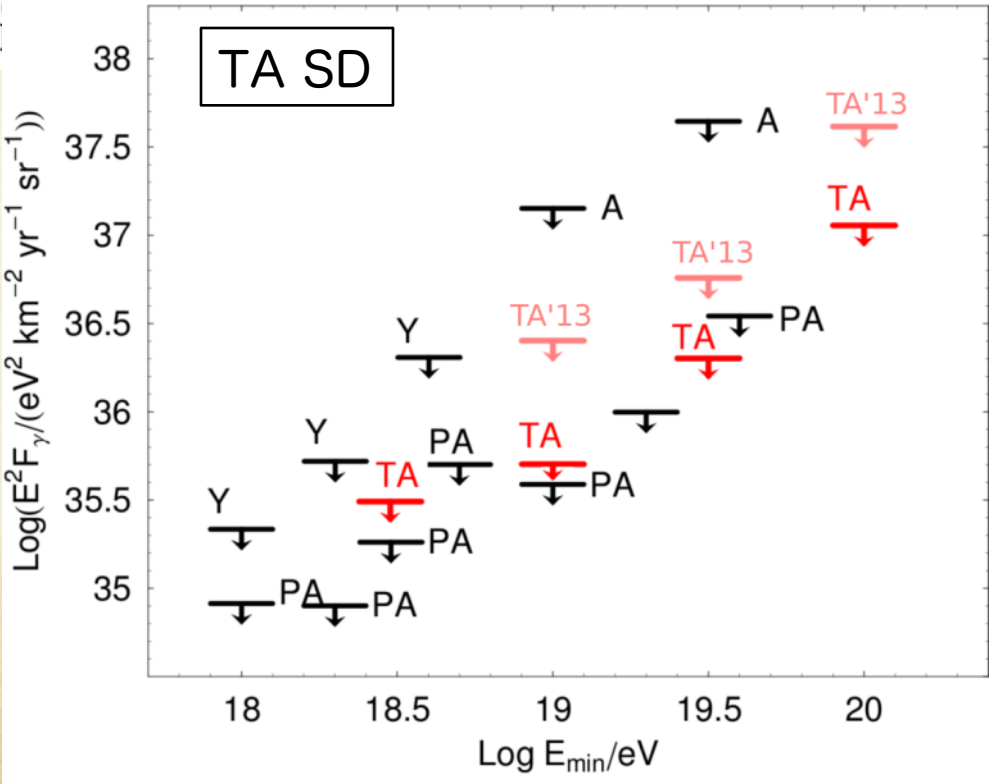
Using Xmax measured by the TA FD





- Young shower
- Less muons

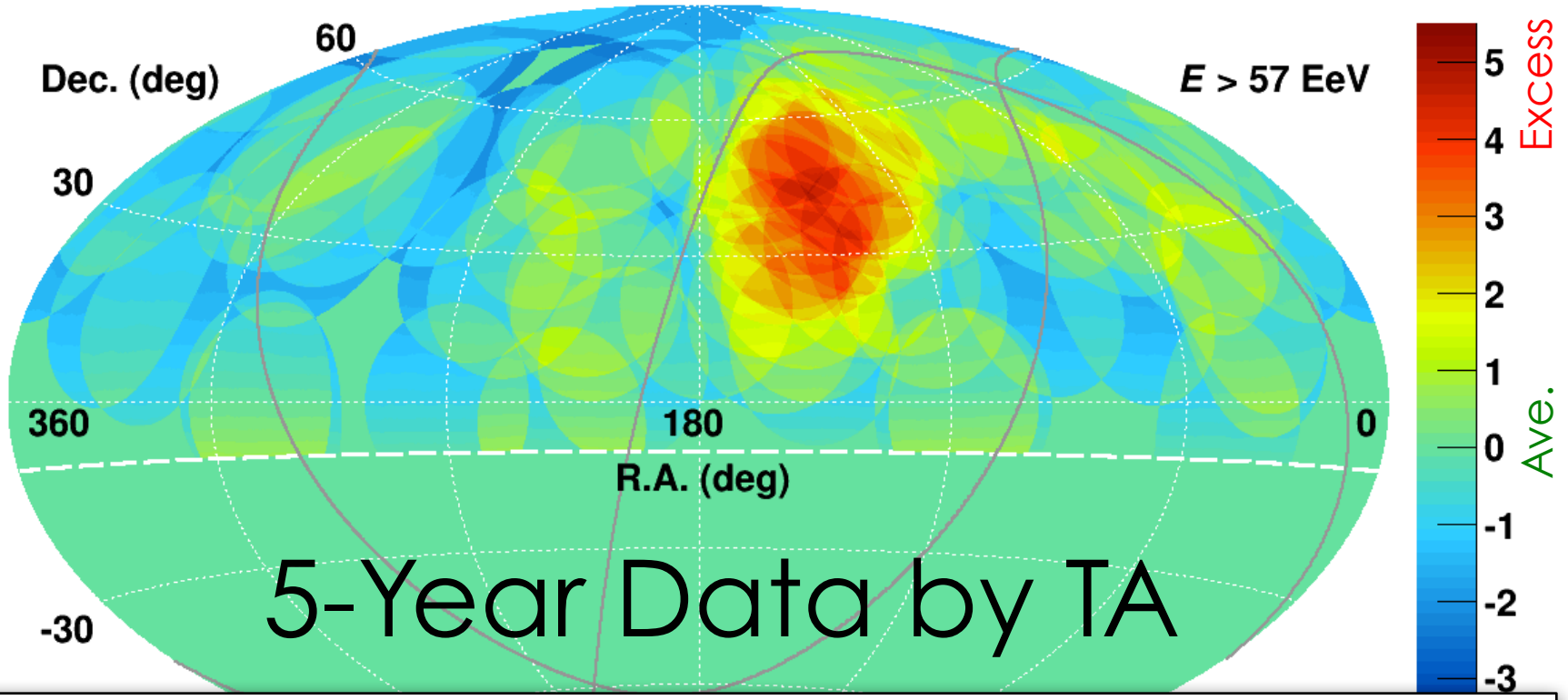
→ front coverture, Area-over-peak, number of peaks in FADC, $\chi 2$



Anisotropy: Hotspot

Previous Report (2014)

Abbasi, R.U., et al., ApJL, 790, L21 (2014)



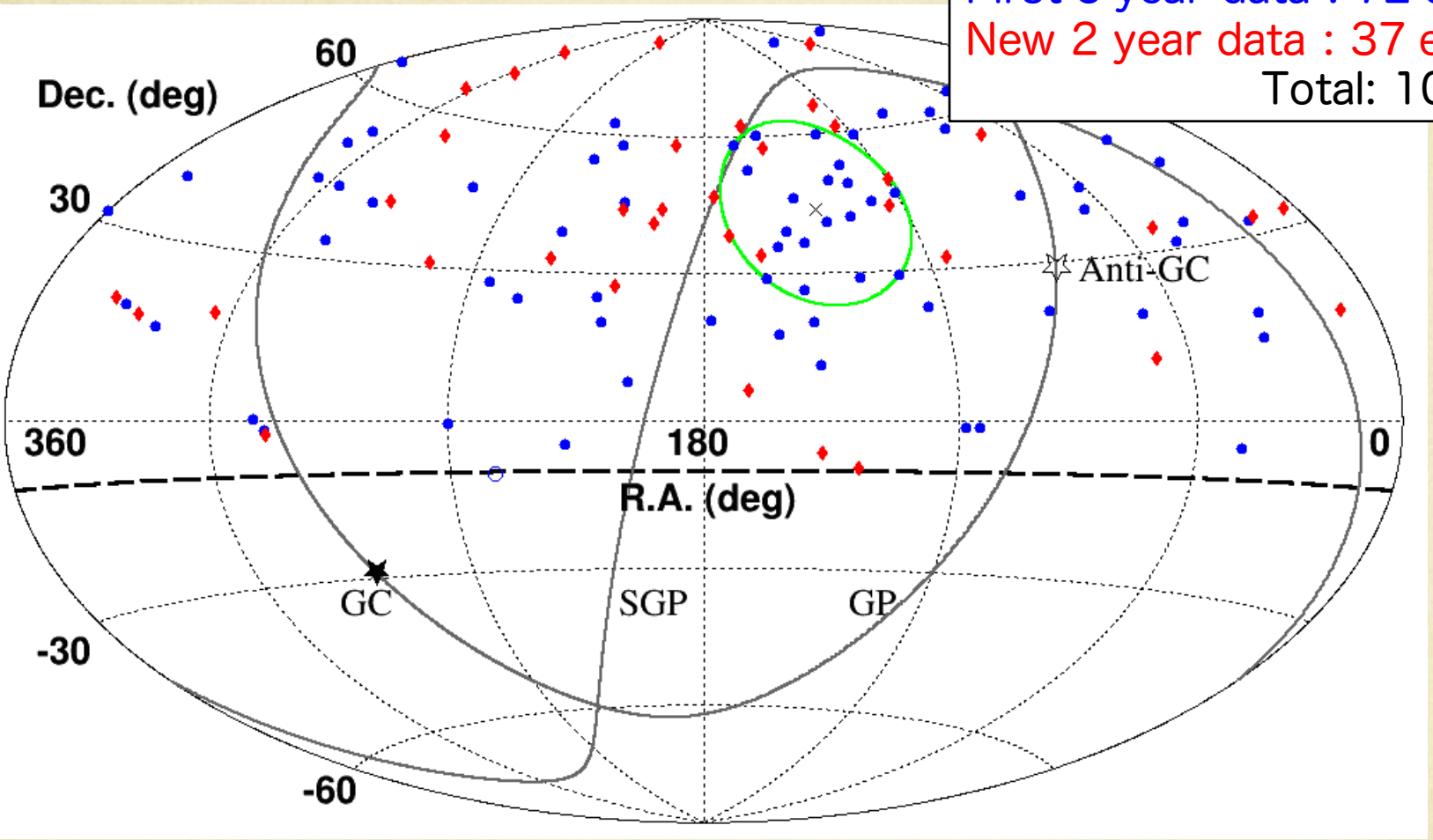
5-Year Data by TA

Procedure:

- TASD data which have more than 57EeV
- Summed in 20 degrees circles (oversampling)
- Significance calculated using Li-Ma : 5.1 σ (pre-trial)
- Chance probability to observe this significance is considered : 3.4 σ (post-trial)

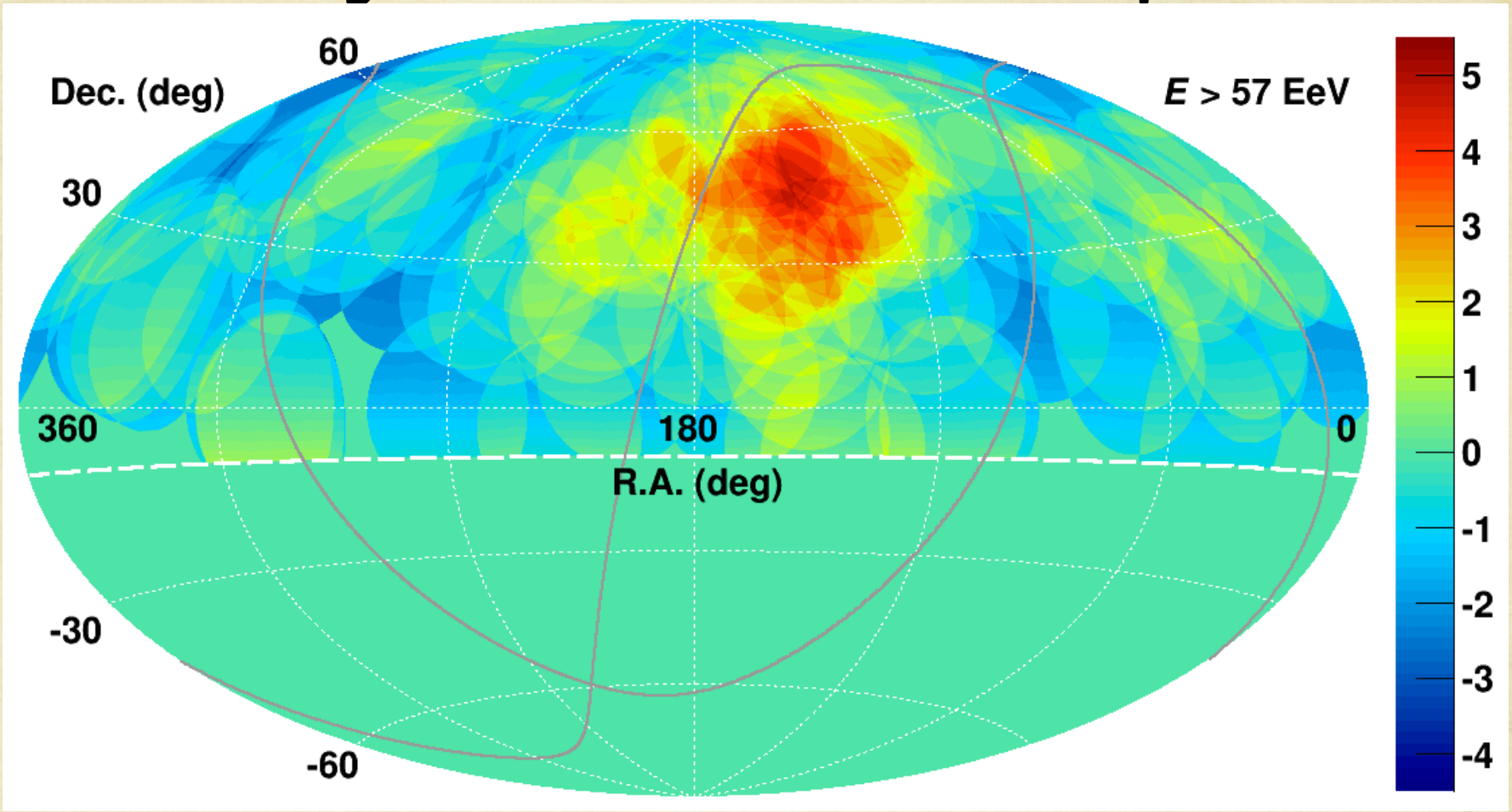
Hotspot update : 7 year

First 5 year data : 72 events
New 2 year data : 37 events
Total: 109 events



Period	Total	Signal	B.G.	Chance Prob.
6-th Year	15	3	0.94	7%
7-th Year	22	1	1.37	74%
6th + 7th	37	4	2.31	20%

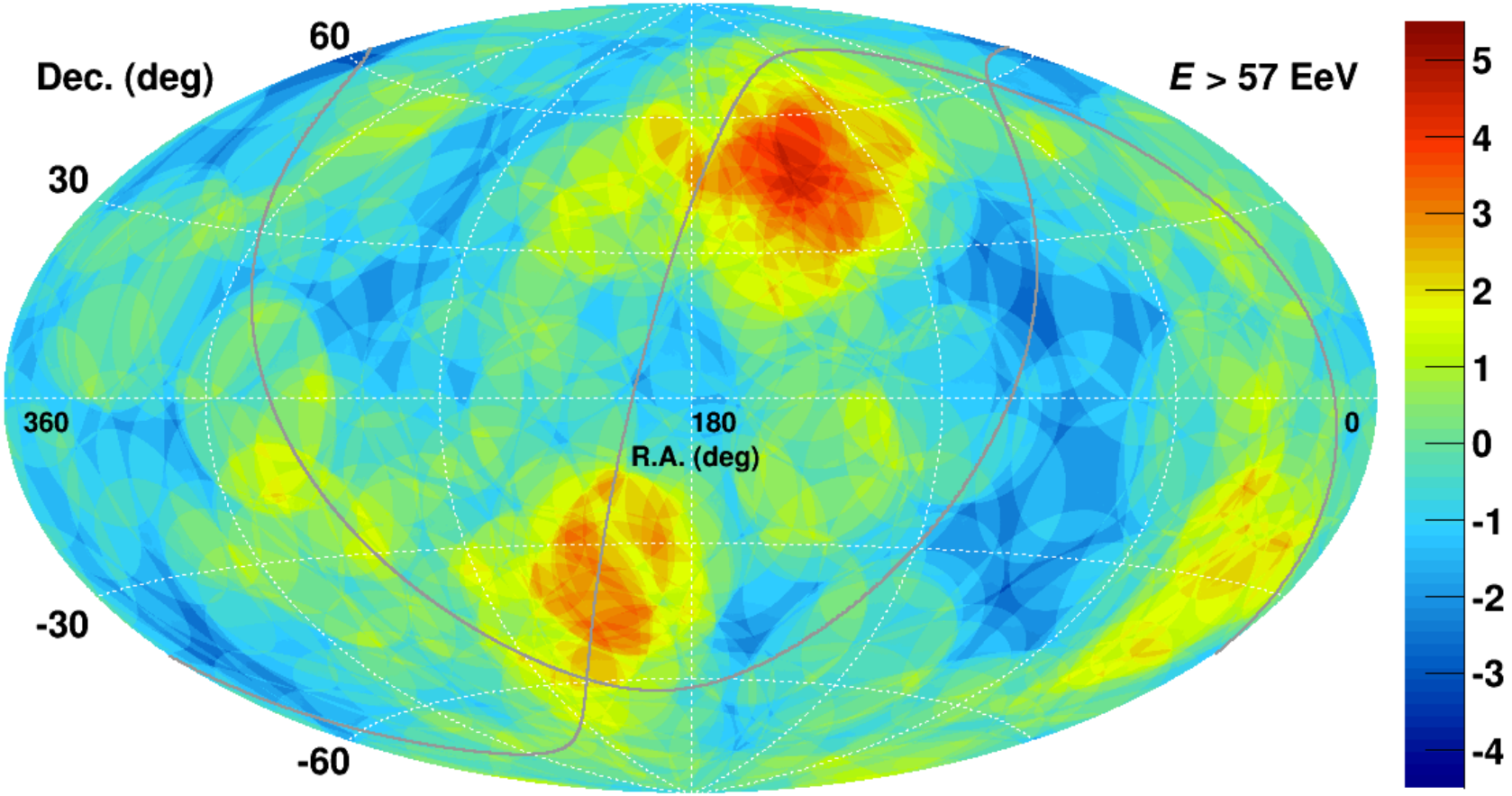
7 year excess map



Max significance **5.1**σ (N_{SIG} = 24, N_{BG}=6.88) for 7 years
Centered at R.A=148.4°, Dec.=44.5° (shifted from SGP by 17°)
Global Excess Chance Probability: 3.7×10^{-4} : 3.4σ
(~ same as first 5 years)

All Sky Survey with TA&PAO

Oversampling with 20°-radius circle



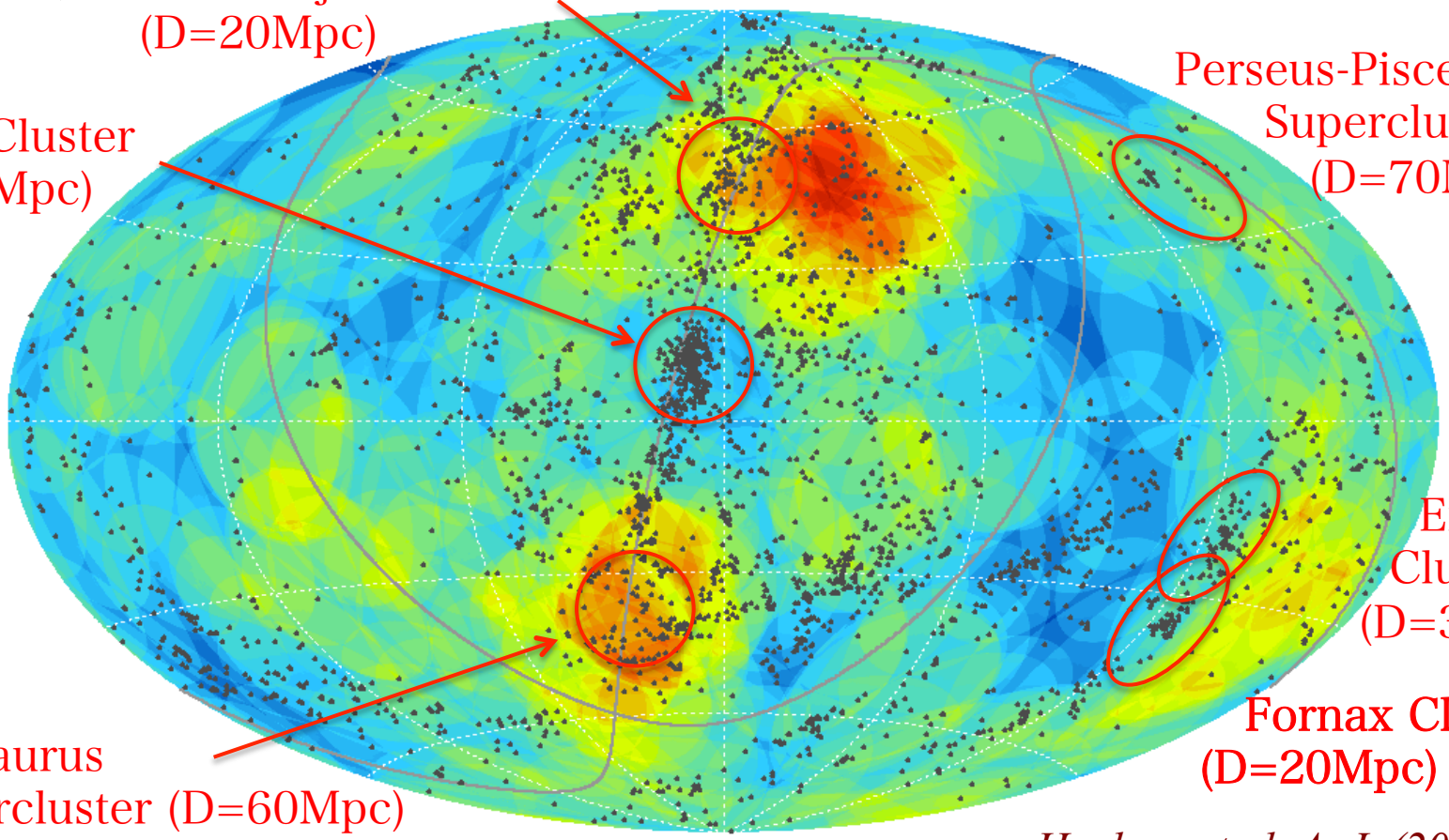
No correction for E scale difference b/w TA and PAO !!

Northern TA : 7 years 109 events (>57EeV)

Southern Auger : 10 years 157 events (>57EeV)

Southern hotspot is seen at Cen A(Pre-trial ~3.6σ)

Nearby Galaxy Clusters



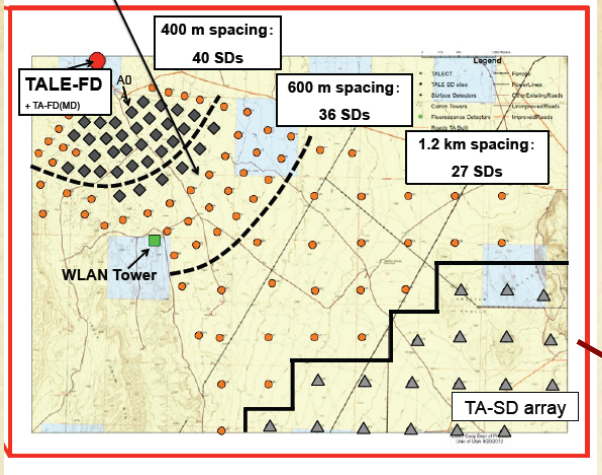
Huchra, et al, ApJ, (2012)

Dots : 2MASS catalog Heliocentric velocity <3000 km/s (D<~45MpC)

TA hotspot is found near the Ursa Major Cluster
TA & PAO found no excess in the direction of Virgo.

Future of TA

TAx4 TALE

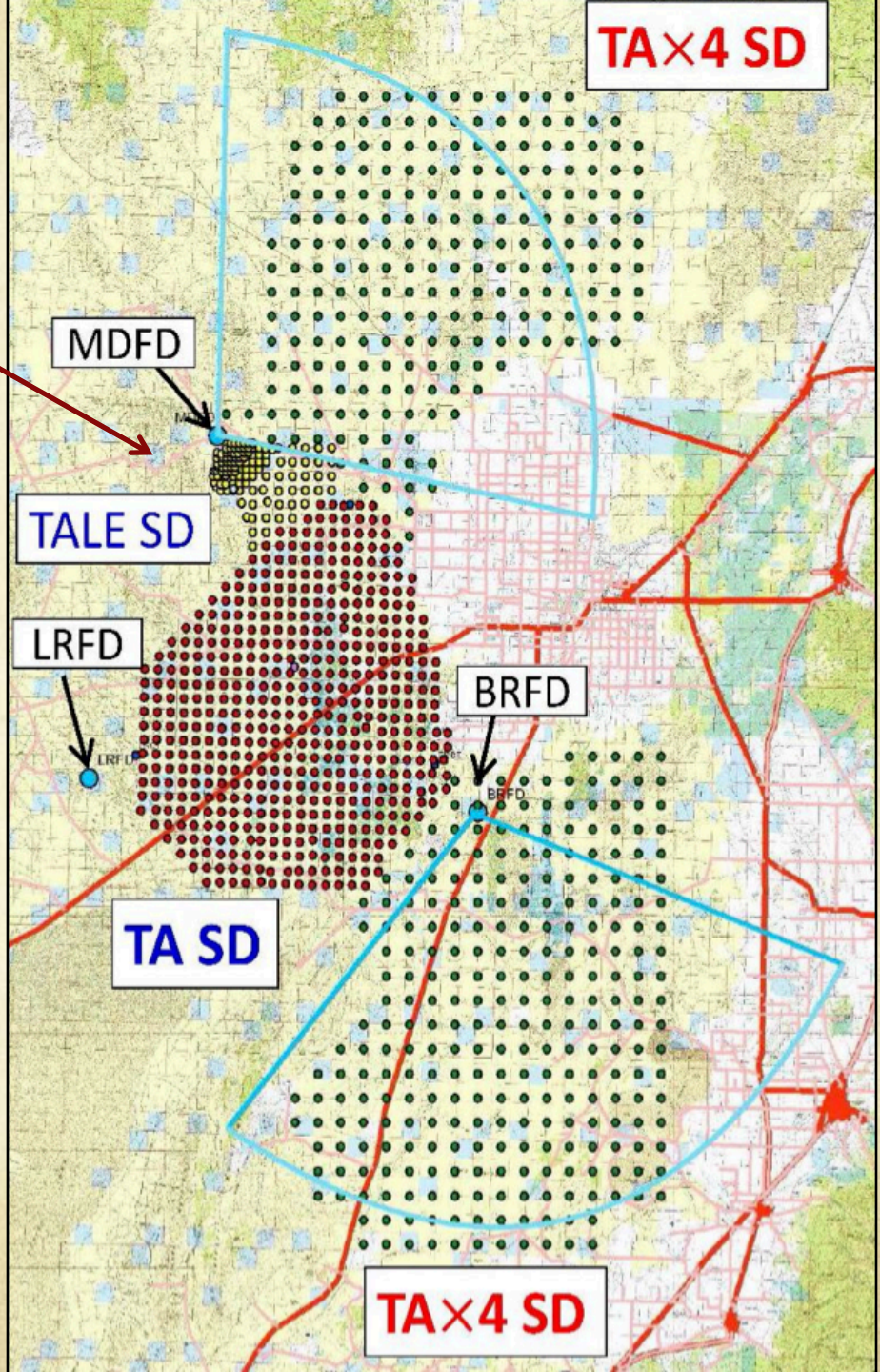


TAx4: High energy extension

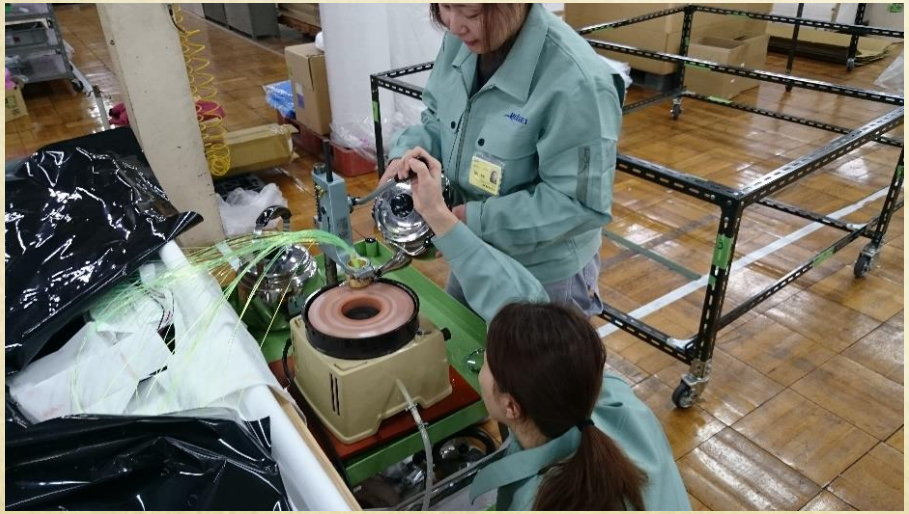
- Quadrature TA SD (~3000km^2)
  - 500 SDs
  - 2.08km spacing
  - Approved in Japan (April 2015)
- Two additional FDs
  - The Utah TAx4 FD proposal has been accepted by the NSF (New!!)

TALE SD: TA low energy extension

- 40 SDs for 400m spacing
- 36 SDs for 600m spacing
- Approved in Japan (April 2015)
- Mode energy of SD: $10^{16.5}$ eV



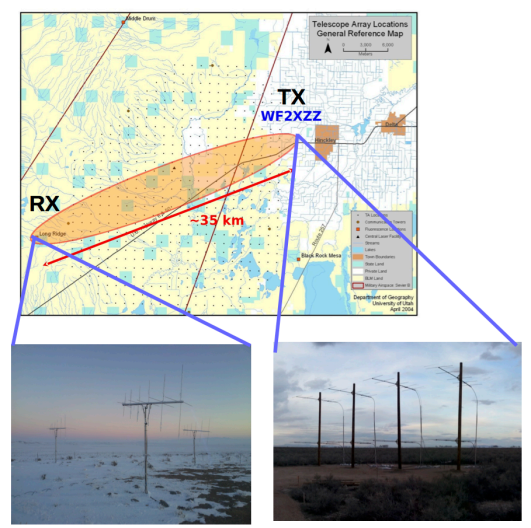
TAx4/TALE detector construction was started !!



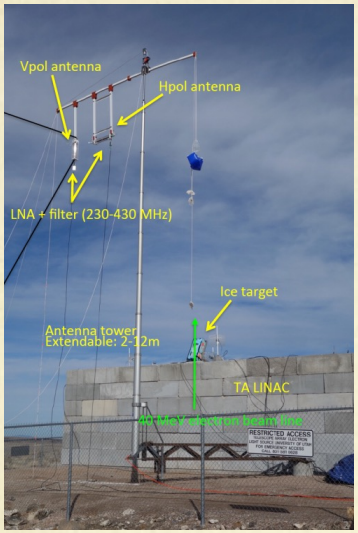
- 100 of SDs has been shipped to Utah
- Additional assemble in Japan is scheduled on next August
- First deployment will be in this winter (depends on the permission from the BLM)

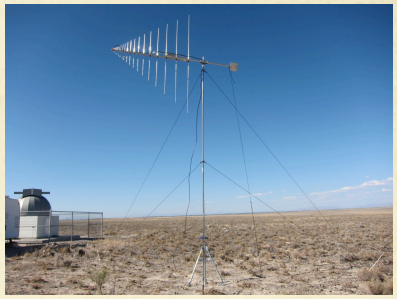
Other activities in TA site

Bistatic radar (TARA)

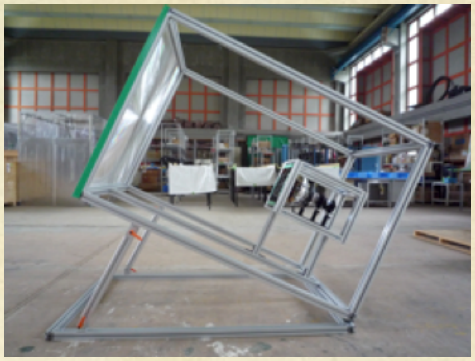


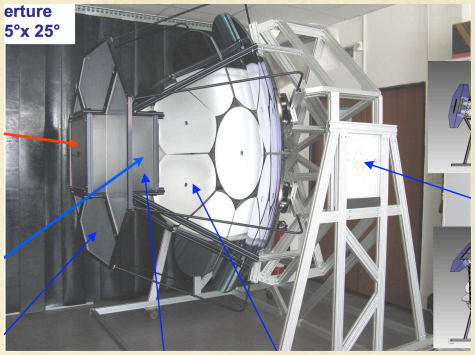
Radio with accelerator





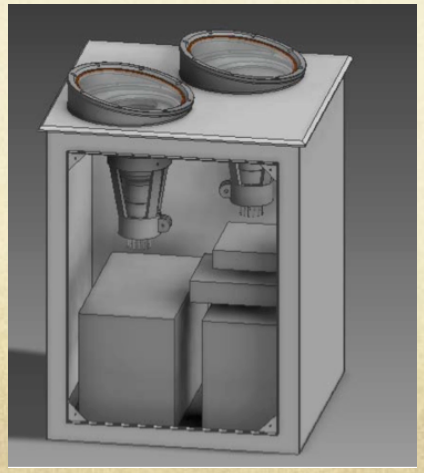
Single (or few) pixel FD





Lightning mapping array (TA-LMA / TA-LLS)

Non-imaging Cherenkov array (NICHE)



EUSO prototype (TA-EUSO)

Summary

- TA entered 9th year of observation

- Physics results:
  - Wide-range energy spectrum which has 4 features
  - “Light” composition from $10^{18.2}$eV
  - p-air cross section at $\sqrt{S}$ = 95TeV
  - Photon upper limit from 10^{18}eV
  - Hotspot in 7 years SD data

- Future of TA: Higher/Lower energy extension
  - TAx4 SD : Approved in Japan (2015)
  - TAx4 FD : Accepted in US (2016)
  - TALE SD: Approved in Japan (2015)